MARGINAL COST FACTORS FOR HIGH PERFORMANCE SHIPS AND THEIR IMPACT ON SUBSYSTEM DESIGN

Douglas Kearney Turner

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AND THEIR IMPACT ON SUBSYSTEM DESIGN

by

DOUGLAS KEARNEY TURNER

B.S., PURDUE UNIVERSITY
(1969)

Submitted in partial fulfillment

of the requirements for the

degrees of

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MARGINAL COST FACTORS FOR HIGH PERFORMANCE SHIPS AND THEIR IMPACT ON SUBSYSTEM DESIGN

By

DOUGLAS KEARNEY TURNER

Submitted to the Department of Ocean Engineering and the Alfred P. Sloan School of Management on May 12, 1978 in partial fulfillment of the requirements for the degree of Ocean Engineer and the degree of Master of Science in Management.

ABSTRACT

Investigation reveals that major weapon, propulsion, and sensor subsystems, selected for use aboard Naval vessels, are designed many years prior to the development of a ship. The tendency, by Ship Acquisition Managers, to select off-the-shelf equipment is the result of various political pressures and a requirement to minimize the technical risk of the total ship system.

Subsystem Designers develop their product without regard for the subsystem's impact on possible future ship designs. The physical characteristics (i.e. weight, required manning, electrical power, and space required) of a subsystem are not controlled and the growth of these parameters is a major factor in the escalating cost of Naval ships.

To assist both the Ship and the Subsystem Acquisition Managers/Designers in controlling costs, Marginal Cost Factors are proposed. Previous work has demonstrated the validity of the concept of Marginal Factors to predict the ship-growth costs due to the impact of subsystems on conventional displacement ships. This thesis builds upon this work by using two ship synthesis computer models to generate Marginal Weight Factors for two high performance ship types of recent interest to the U. S. Navy - Hydrofoils and Surface Effect Ships.

Thesis Co-Supervisor: Cdr. Clark Graham
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Thesis Co-Supervisor: Peter Lorange
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Finally, I dedicate this work to my wife,Maureen and to my daughter, Leigh for their patience and understanding during the many hours of work required to complete this thesis.

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NOMENCLATURE

C_p - Prismatic Coefficient: Displaced Volume of ship divided by midship sectional area times LBP

CNO - Chief of Naval Operations

CSG - Designation used for cruiser sized ships

DD - Designation used for Destroyer sized ships

DE - Designation used for destroyer escort sized ships

FFG - Designation used for Perry Class Frigate

Full Load Disp. - (ΔFL) - Full Load Displacement, in Long Tons

LAMPS - Light Airborne Multipurpose Helicopter

LBP - Length Between Perpendiculars, in Feet

LIGHT SHIP - (LS) - Light Ship Weight, the sum of weight groups 100 through 700 and weight margins, in Long Tons

MWF - Marginal Weight Factor

WEIGHT GROUP - This refers to the weight breakdown by the Navy's Weight Breakdown Structure

WT.GRP.100 (GRP. 1) - Hull Structure Weight

WT.GRP.200 (GRP. 2) - Propulsion System Weight

WT.GRP.300 (GRP. 3) - Electric Power Generation System

WT.GRP.400 (GRP. 4) - Command and Control System

WT.GRP.5XX (GRP. 5XX) - Auxiliaries less Lifting system

WT.GRP.567 (GRP. 567) - Lift and foil systems

WT.GRP.600 (GRP.6) - Outfit and Furnishings

WT.GRP.700 (GRP.7) - Armament Systems

CHAPTER 1.

INTRODUCTION TO THE SHIP/SUBSYSTEM DESIGN PROCESS

GENERAL

There is perhaps no more complex or expensive military system than a naval ship. Consisting of as many as one hundred major subsystems and tens of thousands of individual components, the modern naval ship requires years of detailed planning and several years of actual construction. Currently, the process of creating a new ship, from the early conceptual designs to the delivery of the first vessel, averages seven years. This extended length of time between initial design and product delivery places a significant obstacle in the way of the ship design team to produce a modern naval ship.

U. S. Naval combatants have, since World War II, been increasing in both size and complexity. Reference 2 discusses this increase in size and complexity and attributes the trend to a demand for increased performance by the ship operators. Figure 1.1 (taken from Reference 1) illustrates the trend of increasing ship size over the past 40 years. The only exceptions are the Perry Class Frigate (FFG-7) and the proposed DG AEGIS design both of which are the result of the design philosophy of "Design-to-Cost". Reference 2 describes how this design philosophy resulted in smaller ships than their predecessors.

As discussed above, the increased performance required of ships is a major cause of the larger and hence more costly vessels. This performance increase has been reflected in the characteristics of weapons, propulsion,

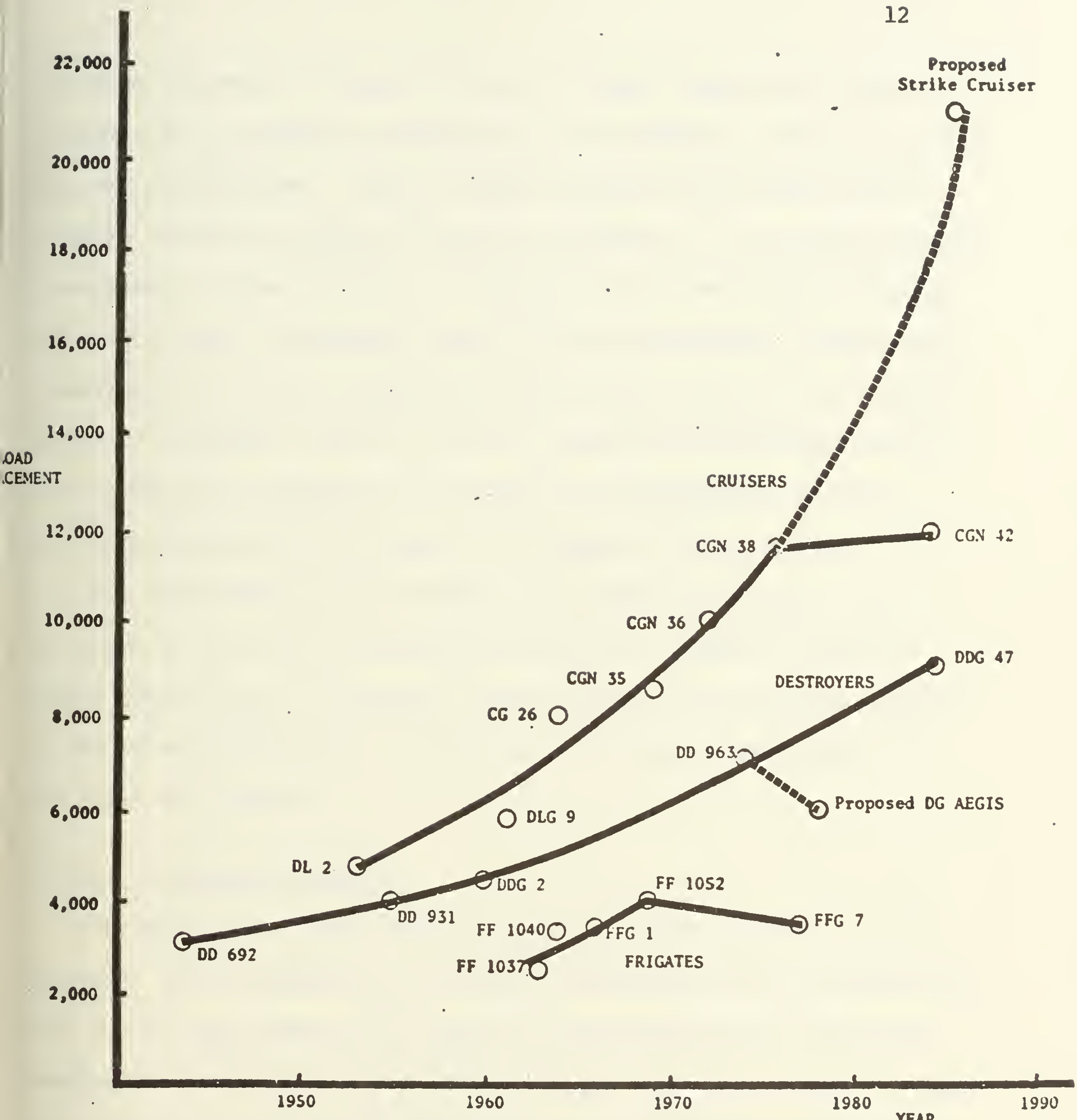


FIG 1.1 - GROWTH TREND FOR U.S. SURFACE COMBATANTS

and sonar subsystems. Figures 1.2 and 1.3 (these Figures were taken from Reference 1) illustrate the changes that have occured to two of a destroyer type ship's subsystems. Note the sharp increase in the sonar's weight, internal volume, and electrical power requirements. It is these increased requirements, typical of many new subsystems, that have greatly affected the ship's size. If the ships' costs are to be controlled, then everyone concerned with the ship acquisition process must be aware of the growing impact of subsystems. That is, not only must the ship designers and the ship operators be cognizant of the effect of subsystems but also the subsystem designers must be aware of the impact of their product.

CDR Clark Graham, USN and others have written (References 1 and 3) at length of the need for cooperation between all members of the ship design community and in Reference 1 Graham stresses the need for awareness by the subsystem designers to understand the impact of their product on the total ship system.

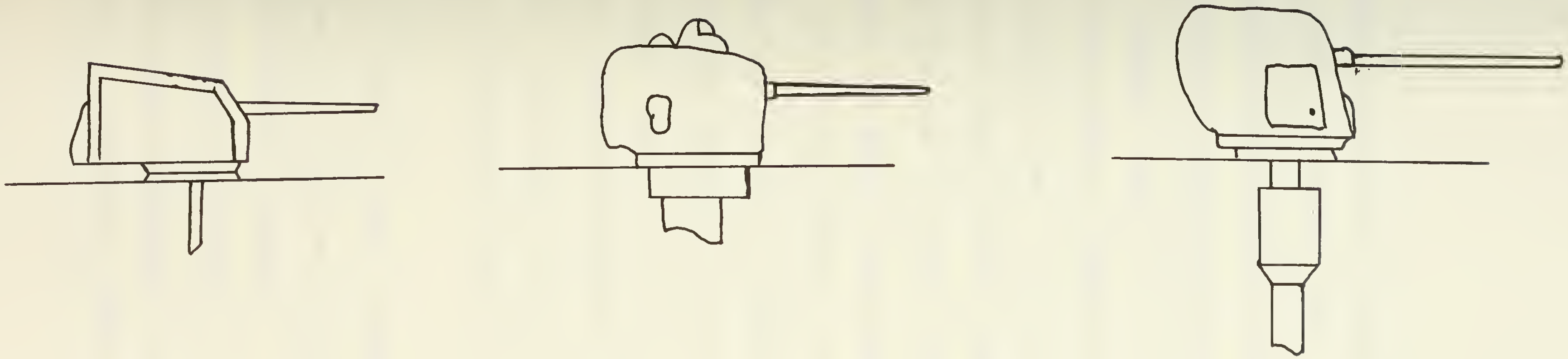
THE SHIP ACQUISITION MANAGER

The design of a modern naval ship has many tasks but two of the most important are the selection of the major subsystems and their intergration into a total ship system. The head of the ship design team is the Ship Acquisition Manager and is responsible for the selection, through a series of tradeoff studies, of the subsystems necessary to accomplish the needed performance capabilities of the ship.

The criteria the acquisition manager uses to select subsystems for a ship has varied with the change in federal administrations. In the mid

SQS 4 SONAR	SQS 23 SONAR	SQS 53 SONAR
Fleet Intro: 1940's	Fleet Intro: 1950's	Fleet Intro: 1970's
Weight: 13 tons	Weight: 28 tons	Weight: 80 tons
Int. Volume: 2,800 FT^3	Int. Volume: 8,000 FT^3	Int. Volume: 21,000 FT^3
Elec. Power: 4 KW	Elec. Power: 36 KW	Elec. Power: 66 KW
Personnel: 6 Men	Personnel: 6 Men	Personnel: 9 Men

Figure 1.2 - EVOLUTION OF SONARS FOR SURFACE COMBATANTS



5"/38 MK 30 GUN MOUNT	5"/54 MK 42 GUN MOUNT	5"/54 MK 45 GUN MOUNT
Fleet Intro: 1940's	Fleet Intro: 1950's	Fleet Intro: 1970's
Weight: 25 tons	Weight: 72 tons	Weight: 46 tons
Int. Volume: 5,700 FT^3	Int. Volume: 7,800 FT^3	Int. Volume: 10,000 FT^3
Elec. Power: 20 KW	Elec. Power: 175 KW	Elec. Power: 150 KW
Personnel: 20 Men	Personnel: 4 Men	Personnel: 2 Men

Figure 1.3 - EVOLUTION OF FIVE INCH GUNS FOR SURFACE COMBATANTS

to late 60's, Secretary of Defense McNamara emphasized the concept of total life-cycle costing. This concept stresses not only the acquisition cost of the total system but also gives equal importance to all operating costs over the lifetime of the ship. The present situation is one of tight budgetary constraints on the ship acquisition funds and has led to the concept known as "Design-to-Cost" which stresses the importance of a low acquisition cost. Within the "Design-to-Cost" environment, the ship acquisition manager selects subsystems that not only have the lowest acquisition cost but should also select the equipments that have a minimum impact on the ship's total acquisition cost.

The foregoing discussion would seem to imply that once the acquisition manager knew the cost of subsystems with similar performance capabilities, the selection decision would be relatively simple. Unfortunately, a subsystem's acquisition cost is only one of the many factors that influence the ship acquisition manager's decision. Reference 4 discusses how subsystems impact a ship design and that the true cost of a subsystem must include both the acquisition cost of the subsystem and its impact on the cost of the ship.

In addition to cost, the ship acquisition manager is constrained by the design philosophy as promulgated by the Chief of Naval Operations (CNO) for the ship being developed. Since the middle 60's, in order to minimize the technical risks inherent in a complex ship system, the utilization of off-the-shelf components for major subsystems has been specified. The reason for this policy is that there are large risks associated with the

the intergration of the separate subsystems into a single entity without having to depend on the concurrent development of high risk components. An example is the design philosophy for the FFG-7 promulgated in July 1971 by the CNO. Among his directions to the ship acquisition manager are:

(1) Favor low acquisition cost over life-cycle costs.

(2) The total ship system is to be optimized rather than optimizing individual subsystems.

(3) Ensure that performance increases are significant in proportion to added investment.

(4) There will be a minimum of future growth margins.

Figure 1.4 presents the development schedule for eight of the major subsystems of the FFG-7 and the design and construction schedule of the ship itself. Note that the majority of the equipments selected were designed prior to the ship in concert with the CNO's design philosophy. The subsystems listed in Figure 1.4 may be divided into three categories.

Developed Prior to Ship Design	Derivative of Earlier Design Developed Concurrently	Concurrent Development
LM 2500 Gas Turbine	AN/SQS 56 Sonar	Fin Stabilizers
MK 32 Torpedo Tubes	AN/SPS 49 Air Search Radar	Computer Software
AN/SPS 55 Radar	HARPOON Missile	
MK 75 OTO Malara Gun	LAMPS MK III	

The FFG-7 acquisition team had no influence on those subsystems developed prior to the ship design and very little influence on the components that were derivatives of earlier designs. Thus although the FFG-7 was

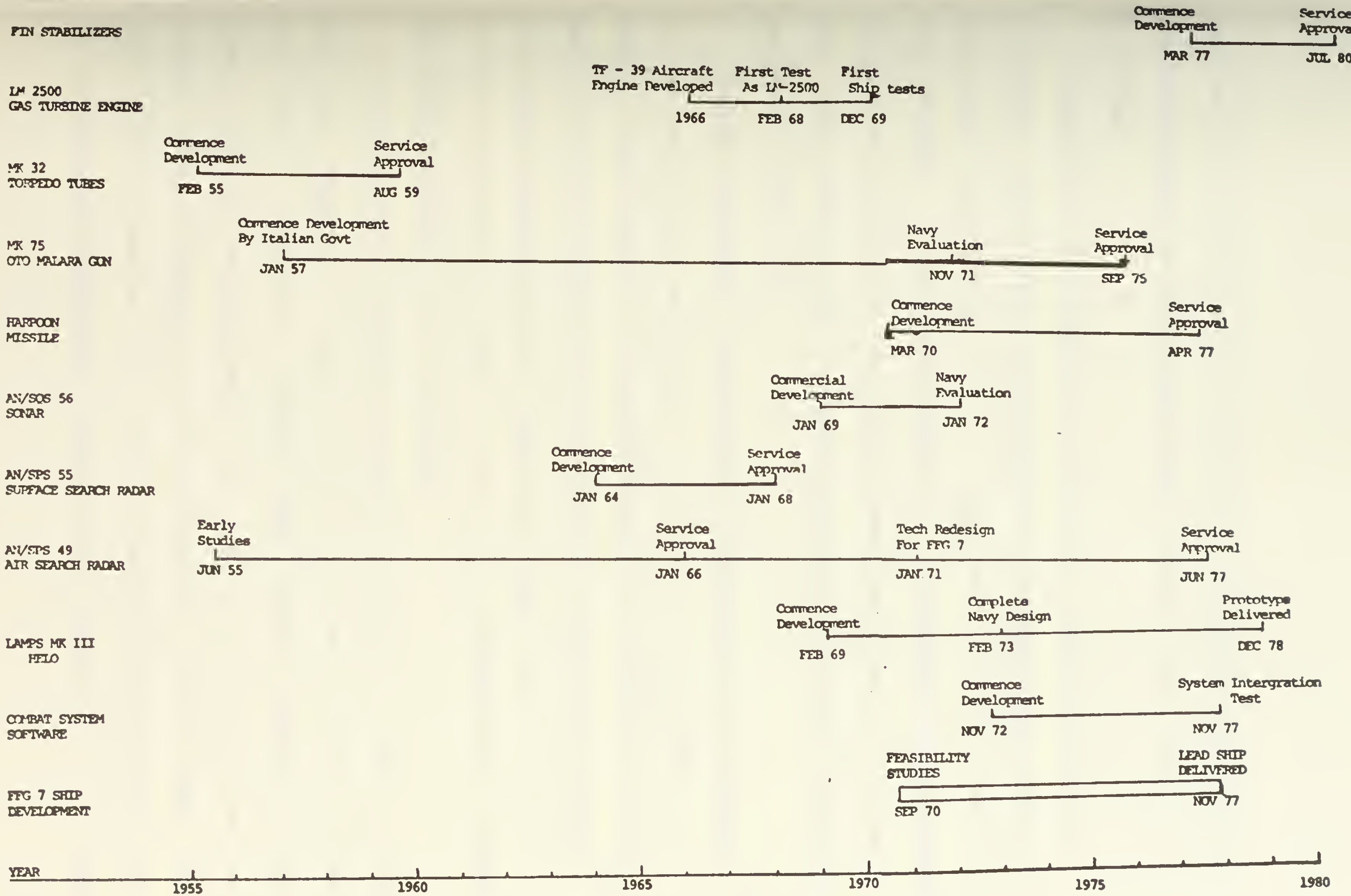


FIGURE 1.4 - COMPONENT AND SHIP DEVELOPMENT SEQUENCE FOR PERRY CLASS FRIGATE (FFG 7)

developed in a "Design-to-Cost" environment, the acquisition manager was unable to control the designs and hence the cost of the majority of the subsystems.

There are two implications to the policy of using off-the-shelf equipments. First, since the subsystems were designed years earlier, the ship design team has no choice but to adapt the ship design to accomodate the subsystems. A second implication is that, assuming a 25 year operational lifetime for the ship, the ship will be using subsystems up to 50 years old. These two implications certainly detract from the Navy's desire to produce an optimum ship.

Another influence on the selection of subsystems for a particular ship is the political environment in which the ship acquisition team operates. For example, a strong consideration in selecting the Italian designed MK 75 OTO Malara Gun was the desire to include NATO equipment on the ship thus enhancing the chances for foreign sales of the FFG-7. Political pressures also exist to select foreign equipment as a "payback" for foreign purchase of U. S. equipment.

A final problem, related to subsystem integration, faced by the ship acquisition manager is the need to reserve space and weight for equipment that is not yet available. The ship design team must encorporate these reservations into the ship design based on the best information available. Inasmuch as most subsystems are not developed for a specific vessel, the ship acquisition manager cannot constrain the subsystem designers to the space and weight reservations incorporated in his particular ship design.

The result is that ships may be delivered with excess space and weight reservations (e.g. FF-1052 for the MK 48 torpedo system) or with insufficient reservations (e.g. DD 963 inability to hangar 2 MK III LAMPS helocopters).

Figure 1.5 presents the development schedule of the Navy's newest destroyer (DD 963) and eight of her major subsystems. The design philosophy of the DD 963, developed in the McNamara era of minimum life-cycle costing, specified a departure from previous ship designs that tried to produce major subsystems and the ship concurrently. That is, maximum utilization of off-the-shelf equipment was required. Another objective, in line with the reduction in life-cycle costs, was the emphasis on reduced demands upon manpower resources. The selection of the MK 45 light weight 5" 54 gun resulted from this reduced manpower requirement; while the selection of the AN/SPS 40B air search radar over the AN/SPS 49 radar reflects the philosophy of using off-the-shelf subsystems vice high risk concurrent development.

The subsystems listed in Figure 1.5 can be divided into the same three categories as was done for the FFG-7.

Developed Prior to Ship Design	Derivative of Earlier Design Developed Concurrently	Concurrent Development
AN/SPS 55 Radar	LM 2500 Gas Turbine	LAMPS MK III
AN/SQS 53 Sonar		
MK 32 Torpedo Tubes		
MK 45 5" 54 Gun		
AN/SPS 40 Radar		
ASROC Launcher		

Note the preponderance of subsystems included in the final design that

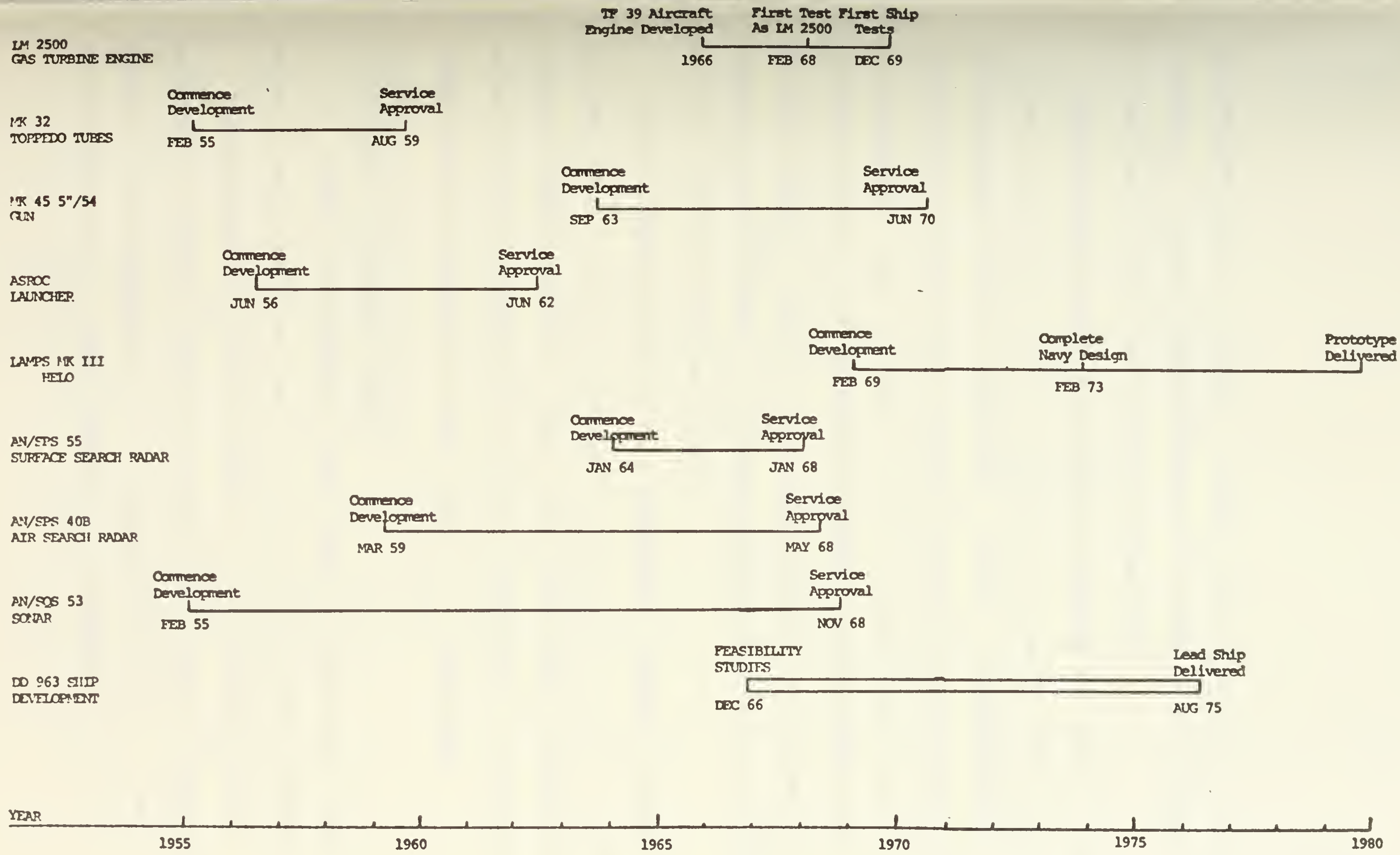


FIGURE 1.5 - COMPONENT AND SHIP DEVELOPMENT SEQUENCE FOR DD 963 DESTROYER

were designed prior to the ship - a direct result of the ship's design philosophy. Only one hardware subsystem, the LAMPS MK III helocopter, can be classified as having been developed concurrently.

The development schedules, depicted in Figures 1.4 and 1.5, indicate that for a subsystem to have any chance for utilization, the equipment must have preceeded the ship in development. Figure 1.6 illustrates the relationship between a single subsystem and several of the host ships for that equipment. Note, in Figure 1.6, that the characteristics of the propulsion plant for each of these four ships were fixed years prior to the ship's design. Therefore, any liasion between the ship acquisition managers and the subsystem's designers would have been akin to closing the barn door after the horse had escaped.

The conclusion is that the ship acquisition team must be able to judge the true impact of various subsystems on their ship in order to conduct accruate tradeoff analyses. However, due to the design philosophy and various political considerations mentioned previously, the ship acquisition manager cannot influence the actual design of the subsystems.

THE SUBSYSTEM ACQUISITION MANAGER

If, as has been previously established, the ships do not affect the design of subsystems, what then influences the subsystem's designers?

Conversations with various members of the subsystem design and acquisition community indicates that there are a number of factors that determine the characteristics of the subsystems produced. A general opinion voiced was that Hull, Mechanical, and Electrical (H M & E)

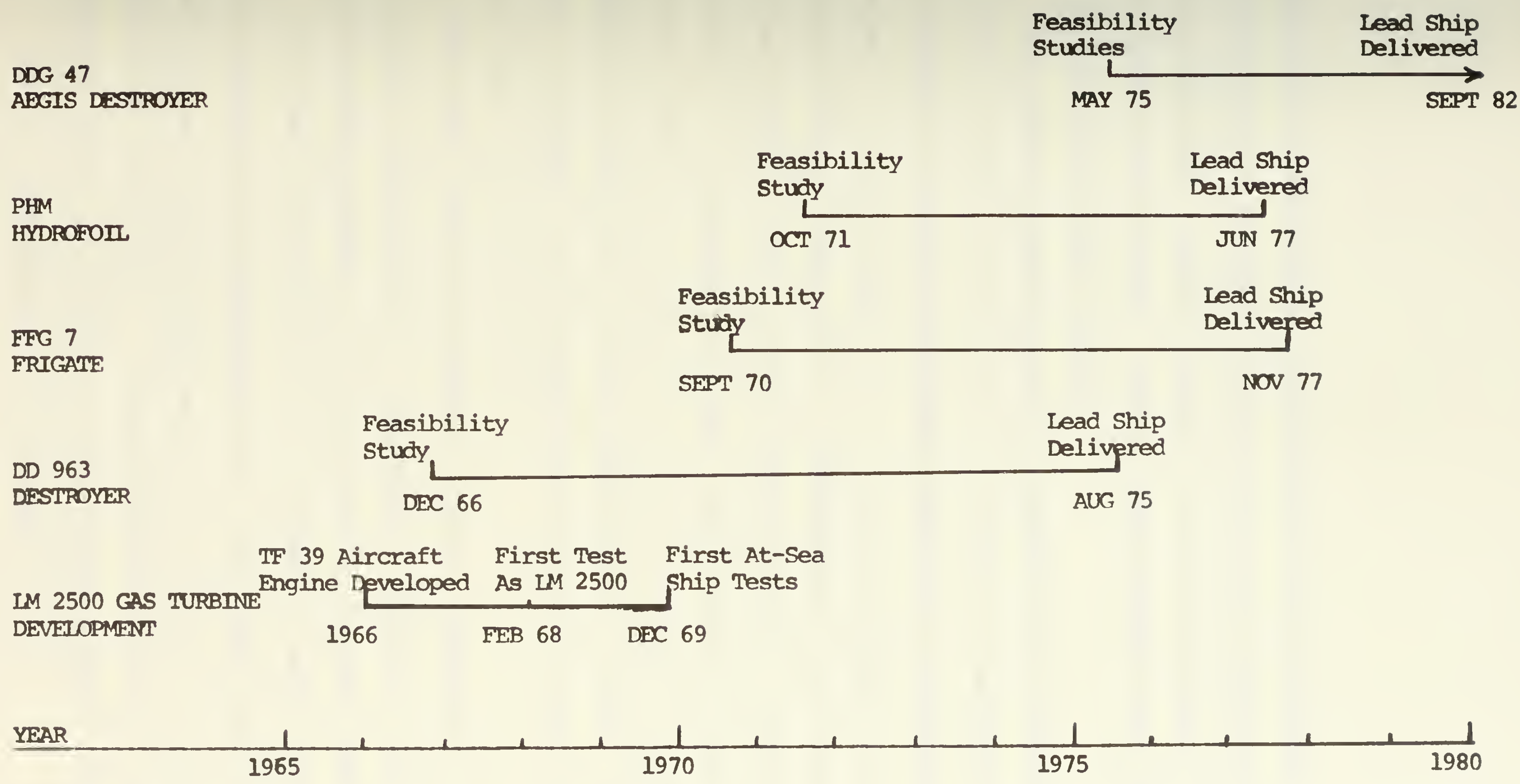


Figure 1.6 - DEVELOPMENT SCHEDULES FOR LM 2500 AND HOST SHIPS

subsystems are developed to take advantage of new technologies - an example being the LM 2500 developed to utilize gas turbines for propulsion. On the other hand, electronic sensors and weapon subsystems are produced to counter specific threats - examples being the newer high performance sonars and cruise missile systems.

The physical characteristics for subsystems may be determined by "in-house studies", the CNO, or more commonly are developedy by contractors in response to performance requirements specified by subsystem acquisition managers. The light weight MK 45 5" 54 gun was developed by the Naval Ordinance Systems Command due to a perceived need by these weapon subsystem designers that to replace the older single 5" 38 gun a lighter version of the MK 42 5" 54 gun would be required. Thus although the MK 45 gun was selected for the DD 963 because of the gun's low manning characteristic, the reason the subsystem was initially developed was to produce a light weight gun. In contrast, the PHM hydrofoil and the FFG-7 did select the MK 45 gun because of the reduced weight.

The Chief of Naval Operations is also often responsible for controlling the physical characteristics of a subsystem. Examples of this situation are the LAMPS helocopter and the cruise missiles currently under development.

The most common situation is that contractors develop subsystems to match performance specifications and few if any limitations are placed on the subsystem's physical characteristics by the Navy. An example is the SQS 56 sonar for the FFG-7. The specifications called for a sonar with the characteristics of the Canadian 505 sonar and the Raytheon company proceded to militarize a previously developed commercial sonar.

A final variation on the origin of subsystems is that of direct supervision by the ship acquisition manager (e.g. the fin stabilizers on the FFG-7) or by the lead contractor that is building a ship (e.g. the anti-submarine rocket (ASROC) loader/magazine on the DD 963). The physical characteristics of the fin stabilizers were directed by the ship acquisition manager to match the space and weight reservations previously designed into the FFG-7. Litton, major contractor for the DD 963, specified the physical characteristics of the ASROC loader/magazine while ensuring that the electrical power requirements were within specified limits and that the space and weight limits would not be exceeded.

The purpose of the foregoing discussion has been to illustrate the variety of situations under which initial development of subsystems may occur. A significant point is that there are many ways a subsystem may originate and that the degree of control the Navy has exercised over the physical characteristics of the equipment does vary.

There seems to be only one general constraint placed on the subsystem acquisition manager that controls the physical characteristics of their products. This constraint is that subsystem designers are enjoined from optimizing an equipment for a single ship or even a single ship type due to the Navy's desire for standardization throughout the fleet. By limiting the variety of equipments, the training requirements and supply support inventories are thereby reduced.

SUMMARY

The current situation in the U. S. Naval ship design community may be summarized as follows:

(1) Ship's are growing larger and hence more costly due to the increasing impact of major subsystems.

(2) Ship acquisition managers, while aware of a subsystem's true impact, has little if any control over the physical characteristics of the equipment.

(3) Equipments are produced by the Subsystem Acquisition Team without regard for their impact on the host ships. This problem is due to the lack of a naval architectural background on the part of the subsystem designers and acquisition managers that would give them an appreciation for the true impact of a subsystem's physical characteristics on a ship's size.

(4) Subsystem designers cannot optimize their product for a single ship type due to the Navy's desires for widespread applicability of the equipment.

(5) The variety of control placed on the design of subsystems increases the difficulty the Navy has in controlling the equipment's physical characteristics. This lack of control is reflected in the increasing impact of subsystems on naval ships.

Graham (see Reference 1) has made two recommendations that would help to alleviate the situation described above. First, a board of review should be created to advise the subsystem design/acquisition community as to the true impact of all proposed subsystems; and secondly, design tools should be made available to all members of the ship/subsystem design community to assist in optimizing the entire ship system.

Having described the current ship/subsystem design problems, this thesis will now proceed to develop design tools for several of the Navy's newest ship types - the Hydrofoil and the Surface Effect Ship. Chapter 2 will discuss the concept of Marginal Factors and their use in the ship/ subsytem design process. Chapters 3 and 4 develop Marginal Weight Factors for Hydrofoils and Surface Effect Ships respectively. Chapter 5 compares the factors for these two ship types with factors previously developed for conventional displacement ships. Finally, Chapter 6 summarizes the results and presents recommendations for further work.

CHAPTER 2.

INTRODUCTION TO THE CONCEPT OF MARGINAL FACTORS

The true cost of a subsystem has both performance and monetary components each of which must be considered when attempting to evaluate the merits of one subsystem over another. Since the difference in performance between subsystems may be slight, often the overriding factor in the selection process becomes the equipment's monetary cost. It is only when this true cost of a subsystem is known, can the ship acquisition manager make the correct decision as to which equipment is to be selected. Furthermore, the true cost can also guide the subsystem designer when deciding on the equipment's physical characteristics.

The total monetary cost of a subsystem is composed of several important sections among which are the life-cycle costs and the ship-growth costs. Life-cycle costs include the equipment's cost of acquisition, repair and maintenance costs, personnel costs, and other operating costs over the lifetime of the equipment. A subsystem's acquisition cost is an expense over which the ship acquisition manager has little control (except to select the cheapest system) since he normally selects off-the-shelf equipment. On the other hand, the subsystem designer can control much of the acquisition cost. Specifications requiring miniaturization of the equipment, excessive reliability, low weight, and low manning can all increse the subsystem's acquisition cost. In contrast, high reliability and low manning will decrease the other components of life-cycle cost implying that a trade-off is required.

Ship-growth costs are costs that result from the necessity of a ship to resize in order to accomodate a subsystem. For example, the weight of an equipment causes the ship to grow to support the weight thus increasing the hydrodynamic drag which causes the propulsion plant and hence fuel weights to increase. These ship-growth costs can have a substantial impact on the ship's life cycle costs and must therefore be taken into account when computing the total cost of a subsystem. Graham, in Reference 1, illustrates the growth in size of naval ships and relates the cause to increased performance requirements demanded of the subsystems. If the total impact of the subsystems on the ships had been fully understood, it is quite likely that different decisions would have been made regarding the design and/or selection of specific equipments.

In order to support the decisions made by the ship acquisition managers and the subsystem designers marginal "cost" factors have been developed. It is the ship-growth costs that can be estimated through the use of these factors. Marginal "cost" factors refer to the incremental change in "cost" due to one additional unit of a parameter at some specified level. The quote marks are intended to indicate that cost may not be strictly money but instead may refer to a weight or performance "cost". An example of a marginal "cost" factor for payload weight would be the change in the ship's full load displacement in response to a unit change in the military payload's weight. To avoid confusion, the term "marginal weight factor" will henceforth be used when the "cost" is a change in the ship's full load displacement.

Marginal weight factors (MWF) have several advantages over monetary factors in the areas of both their use and their generation. A subsystem having a total weight impact of 20 tons on a ship's size in 1975 will have the same impact in 1980. On the other hand, the monetary cost impact will vary according to labor and material cost escalation and inflation indicies. This characteristic of monetary cost factors to vary with time, complicates their use and makes comparisons difficult. Cost has been found to be a direct function of weight hence a change in weight can be interpreted to mean an increase in cost. Furthermore, the ship designer may be working with a constraint on the ship's weight and money may be of secondary importance at his level. If actual monetary costs are desired, the conversion from weight to dollars is a relatively simple procedure given the availability of a weight sensitive cost estimating model.

It was originally intended to produce both marginal weight factors and marginal cost factors that would relate the change in the ship's full load displacement and the total life-cycle costs. However, it was found that cost models for high performance ships are not readily available and much of the information in this area is considered proprietory. It was therefore decided to generate only the marginal weight factors for hydrofoils and surface effect ships. These two ship types were chosen for investigation due to the U. S. Navy's recent interest in these ships and to complement marginal weight factors previously developed (see References 4, 5, and 6) for conventional displacement ships.

Previous work in the area of marginal weight factors has determined that the impact of a subsystem added to or removed from a ship may be adequately described by four payload support parameters. They are:

- Weight
- Manning
- Electrical Power
- Space

James Sedj, a naval architect in the Advanced Ship Development Programs Office of the Naval Sea Systems Command, was the first to systematically produce marginal factors for the above mentioned payload support parameters and to demonstrate their use in conducting trade-off analyses between several subsystems. Sedj generated marginal cost factors with the aid of DD07, a computer ship synthesis model for conventional displacement ships developed by the Naval Ship Engineering Center, and a weight-based cost estimating model. The results were presented at the 11th annual Symposium of the Association of Senior Engineers in a paper entitled "Marginal Cost - A Tool in Designing to Cost".

An M.I.T. masters thesis by Jay Howell in 1976 (Reference 5) expanded upon Sedj's work by generating marginal weight factors for three baseline ships of varying displacement. Howell used DD07 to study the relationship between the size of the factors and a ship's size. Marginal weight factors were produced for the four payload support areas of weight, manning, electrical power, and space. A summary of his results may be found in Appendix I.

The generation of marginal weight factors requires the use of ship synthesis models capable of producing minimum weight designs subject to performance and naval architectural constraints. Sedj and Howell both used DD07 to compute MWF's for displacement ships in the range of 3500 tons to 12,000 tons full load displacement. There are two key characteristics of a ship synthesis model that must be present if the model is to be used to generate marginal weight factors. First, the model must produce as an output a minimum displacement design; and second, the user of the model

must be able to vary, as an input, the parameters of interest (i.e. payload weight, manning, electrical power, and space).

Given a computer ship synthesis model with the characteristics described above, it is a relatively simple procedure to compute marginal weight factors. A baseline ship is first produced with a given payload size, physical characteristics, and performance requirements. The design of this baseline ship then becomes a reference from which the marginal factors are generated. The next step is to input a change to one of the parameters while keeping the other parameters and the ship's performance constant. The ship's physical characteristics are allowed to vary and the computer model produces a new minimum weight design. This procedure is repeated for several variations (both positive and negative) of the parameter being investigated and the differences between the weight of the new designs and the baseline are plotted versus the corresponding change in the parameter. The slope of the plot of change in full load displacement versus the change in support parameter is the marginal weight factor - the change in full load displacement associated with a unit change in the support parameter. If the ship synthesis model provides the user with a breakdown of the components of the full load displacement, marginal weight factors may also be computed for any of these components. For example, it is often of interest to know the MWF for fuel since this is becoming such a large expense item in a ship's total life-cycle cost.

The final product consists of a set of four MWF's (payload weight, manning, electrical power, and space) for each of the baseline ships being considered. These factors may then be used to determine the total impact

of a subsystem on a ship. An example that illustrates the use of marginal weight factors to predict the growth in the full load displacement of a U.S. Navy Destroyer is shown below in figure 2.1.

Payload Characteristics		Destroyer's MWF's	
Weight	= 50 tons	Weight	= 2.200 tons/ton
Manning	= 3 men	Manning	= 4.450 tons/man
Electrical Power	= 100 KW	Electrical Power	= 0.109 tons/KW
Space	= 500 FT^2	Space	= 0.036 tons/FT^2

Impact Due To:

Payload Weight:	50 x 2.2	= 110 tons
Manning:	3 x 4.45	= 13.35 tons
Electric power:	100 x .109	= 10.9 tons
Space:	500 x .036	= 18.0 tons
Total Impact		= 152.25 tons

Figure 2.1

Impact of a payload on a ship's full load displacement

Frank Bryant, in a 1976 M.I.T. Engineers thesis (Reference 6), investigated the mechanics of using marginal weight factors, the assumptions inherent in them, and limitations on their use. Bryant investigated the validity of five assumtions concerning marginal weight factors and their use. The five assumptions are:

(1) The summation of individual parameter impacts to find the total equipment impact is valid.

(2) The marginal weight factors take into account both direct and indirect effects of the equipment addition.

(3) The marginal weight factors are valid and constant over the range of equipment direct support parameters.

(4) The marginal weight factors are valid for the equipment type or ship feature being evaluated.

(5) The four payload support parameters of weight, manning, electrical power, and space adequately describe the equipment's impact on a ship.

He found that these assumptions are generally valid but that some minor limitations exist when MWF's are used to predict the total impact of an electronic subsystem on conventional displacement ships.

Sedj also noted several limitations to the use of MWF's for the subsystems under consideration.

(1) The subsystem must be independent in that the selection of one does not demand the selection of another supporting subsystem.

(2) At least one of the subsystem's support parameters must be identifiable (e.g. weight, etc.).

There are three additional areas of concern that should be considered when using marginal factors.

(1) Marginal weight factors for the various payload support parameters may be valid only within the range investigated. That is, at

some limiting value of the support parameter the plot of change in full load displacement versus the change in support parameter becomes non-linear to the point where the MWF is no longer accurate. Howell did attempt to find points of non-linearity for the payload support parameters on conventional displacement ships and reported his findings in reference 5. The full load displacement of hydrofoils was found to vary linearly with the change in all four support parameters for all ranges investigated. No linearity checks were made for Surface Effect Ships due to funding limitations and the MWF's should be considered accurate only over the ranges investigated.

(2) To capture the effect of increasing propulsion plant size it was necessary to have the baseline ships fitted with "rubber" engines. That is, the weight of the propulsion plant varied with the required shaft horsepower. If the propulsion plant was not "rubberized", then quantum jumps in plant weight would have occured whenever the baseline propulsion capacity was exceeded. The result is that at times the computer will overestimate the total weight impact and at other times it will underestimate the impact.

(3) A final point to consider when using marginal weight factors is that the value of the MWF is highly dependent upon the characteristics of the baseline ship. The user of the MWF's should therefore carefully judge how closely the baseline, used to generate the factors, matches the vessel under consideration. Depending on

the degree of accuracy required, a ship acquisition manager may have to generate new MWF's for his specific ship. A subsystem designer should be able to conduct evaluations of his product on various ship types and sizes without recalculating the factors produced by Howell or those generated by this thesis.

Marginal weight factors can be of value to the ship acquisition manager in conducting a trade-off analysis between subsystems of comparable performance. By applying marginal weight factors for the applicable ship type and size, the true impact of the candidate subsystems can be accurately determined.

As discussed in the previous chapter, the subsystem designers have not heretofor had adequate tools to assist the designers in producing minimum impact equipments. If the equipment designer could accurately judge the true impact of his product on potential candidate ships, the product would be assured of wider usage and aid in producing minimum cost ships. Not only can a subsystem designer optimize his product for a specific ship type, but he can also produce a minimum impact product for all ship types thus increasing the potential applications for his product.

CHAPTER 3.

MARGINAL WEIGHT FACTORS FOR HYDROFOILS

INTRODUCTION

This chapter describes the generation of marginal weight factors for hydrofoils. The factors for the payload support areas of weight, manning, electrical load, and space were computed with the aid of the Hydrofoil Analysis and Design (HANDE) computer ship synthesis model. An explanation of this computer model, the methodology used, and the actual calculations are provided to assist readers in adjudging the accuracy and applicability of the marginal factors that were generated. Because the hydrofoil is a high performance ship and is weight sensitive, it was anticipated that the marginal weight factors would be larger than those of conventional displacement ships. In general, this was found to be true; although the marginal weight factor for electric load was lower than expected.

A hydrofoil operates by lifting its hull clear of the water which significantly reduces the hydrodynamic drag. This drag reduction allows the hydrofoil to attain speeds in excess of fifty knots with a moderately sized propulsion plant. While operating in the foilborne mode, the hydrofoil is supported by the dynamic lift generated by the foils. When hullborne, the ship operates as a conventional displacement ship with the vessel's weight being supported by the buoyant forces only.

"HANDE" SHIP SYNTHESIS MODEL

To investigate the impact of a payload's support parameters (i.e.

weight, manning, KW load, and space), the use of a computer ship synthesis model is essential. Because of the model's ease of operation, its relatively low operating cost, and the ability to fix operational requirements and solve for the resulting minimum weight ship, the HANDE program was chosen.

HANDE was developed by the Boeing Company under a U. S. Navy contract and provides a fast, consistent, and an easily-used ship design tool. The model intergrates existing hydrofoil technology to produce consistent hydrofoils designed to meet specified mission requirements.

A detailed description of HANDE is found in Reference 7; however, a brief summary of the applicable portions is presented below.

As illustrated in Figure 3.1, HANDE consists of three major sections - Initialization, Synthesis, and Analysis. Each of these sections may be used individually depending upon the level of detail or specific application desired.

The Initialization section uses parametric methods to provide initial ship size or performance estimates depending on the mode selected. Initialization also generates a detailed estimate of the volume and space required based upon the characteristics of the ship being investigated. The space required is based on the Highly Sensitive Ship Synthesis Model for Surface Combatants developed by NAVSEC. These relationships have been modified to introduce mission duration sensitivity and to be appropriate for hydrofoils up to 3000 tons. After investigations indicated that the Initialization module could be used for high level

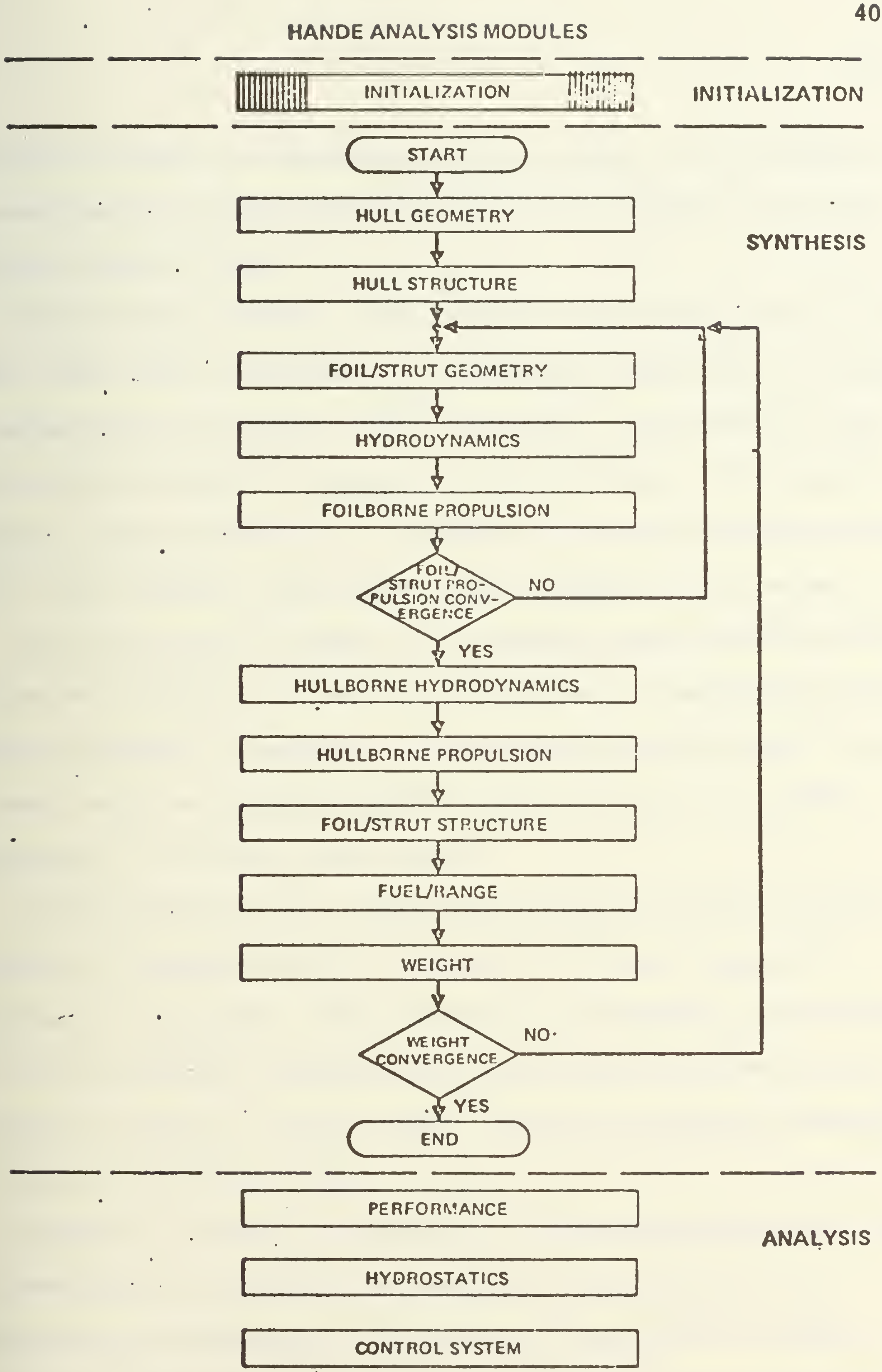


Figure 3.1 - HANDE ANALYSIS MODULES

parametric studies with reasonably accurate results, it was decided to generate marginal weight factors for hydrofoils using this relatively low-cost section of HANDE.

The Synthesis section of HANDE consists of ten modules each of which may be used either individually to investigate a single area of a design or sequentially, to design a complete hydrofoil. Two iterative loops are provided to ensure an internally consistent design. The Synthesis section, while considerably more expensive to run than the Initialization module, does provide a much greater level of detail to the designer.

The final section of HANDE is the Analysis section and may be used to provide information relevant to the ship designs generated by the two previous sections. For example, the designer can use the Analysis section to check static and dynamic stability characteristics or to predict performance in a variety of sea states.

As discussed above, the Initialization module provides a detailed breakdown of required volume as a function of the ship's size and performance requirements. This information is furnished to the designer so that he may manually converge the volume required with the volume available to produce a "tight" design. There is no automatic convergence of volume in the HANDE program.

Appendix II contains a description of the Initialization section and an investigation to ascertain the accuracy of this section. The investigation indicated that Initialization is accurate for designs of less than 1500 tons. Above this point, however, the Initialization section increasingly underestimates the ship's size and the Synthesis

section must be used.

Because of funding limitations and the demonstrated suitability of the Initialization module over a wide range of hydrofoil sizes, it was decided to use the Initialization section of HANDE to generate marginal weight factors for hydrofoils. The data generated by Initialization for the 2600 ton hydrofoil will be reported in addition to results computed by the Synthesis section.

BASELINE HYDROFOILS

To avoid masking trends within the data, the selection of consistent baselines is a vital first step in the generation of marginal weight factors. The baselines had to cover a wide range of displacements with each design being a logical and "typical" hydrofoil for that size ship. That is, a 300 ton hydrofoil could not be given the same performance requirements as a 3000 ton vessel while at the same time items such as propulsion plant type had to remain constant across all baselines. The resulting baselines meet these requirements and their characteristics differ only as a logical function of a changing displacement.

At the time this thesis was being researched, the Hydrofoil office at the David Taylor Naval Ship Research and Development Center (DTNSRDC) was preparing a paper for presentation in April of 1978 at the American Institute of Aeronautics and Astronautics annual meeting. The title of the paper is "Balancing Mission Requirements and Hydrofoil Design Characteristics" and used the HANDE ship synthesis model to modify the operational requirements of hydrofoils of varying displacements. The

baselines used for their paper were selected for use in this thesis. In addition to the fact that the baselines were readily available, the baselines represent the output of a skilled group of engineers, extremely knowledgeable in the intricacies of hydrofoil design.

A detailed description of these baselines may be found in Reference 8. The summary of the baselines' operational and physical characteristics are contained in Tables 3.1 and 3.2.

METHODOLOGY

Inasmuch as the HANDE data base contained four baseline hydrofoils, the only tasks required to generate data for the calculation of marginal weight factors for payload weight and crew size were to input the desired perturbations, note the results, and plot the data. Since HANDE does not provide for either electrical load or space as inputs to the model, marginal weight factors for these two parameters were generated through a combination of hand calculations and the HANDE output.

No modifications were required to the HANDE program. The mode selected for the Initialization runs was "Input range, calculate fuel and ship weights". Payload weight was varied by adding to and subtracting from WT.GRP.700 and variations of ± 100% of WT.GRP.700 were investigated. An example illustrating a payload weight perturbation for a single baseline hydrofoil is described below.

(1) Load the specific baseline from the data base as the "reference" ship.

Table 3.1

Baseline Ship Characteristics

	SHIP DESIGNATION			
	30BL	60BL	120BL	240BL
PHYSICAL CHARACTERISTICS				
LBP (feet)	129	170	226	270
Hull Beam, maximum (feet)	32	38	46	53
Foil Span, maximum (feet)	43	61	86	118
Draft, Foils Down (feet)	25	34	38	41
C_p	.623	.623	.623	.623
Hull Draft, Foils Up (feet)	6.7	8.3	11.0	13.9
Full Load Displacement (tons)	298	674	1350	2613
Total Enclosed Volume (ft^3)	46100	91500	179000	305000
Foil Lift Distribution, Fwd/Aft%	33/67	40/60	40/60	40/60
CREW SIZE				
Officers	5	6	10	14
Chief Petty Officers	4	5	6	12
Enlisted	12	34	68	114
TOTAL	21	45	84	140

Table 3.2

Baseline Ship Characteristics

	SHIP DESIGNATION			
PERFORMANCE	30BL	60BL	120BL	240BL
Mission Duration (days)	10	20	30	30
Foilborne Speed (knots)	50	50	50	50
Foilborne Range (NM)	1500	2000	2500	3000
Hullborne Speed (knots)	15	15	15	15
POWER DATA				
Installed FB SHP	12754	26886	48664	92898
Installed HB SHP	2678	4164	5730	8892
Installed Electrical KW	431.3	808.1	1134.9	1643.5
WEIGHT DATA				
Hull Structure (WT.GRP.100) (tons)	50.7	102.8	191.3	328.0
Propulsion (WT.GRP.200) (tons)	31.7	56.8	90.8	155.2
Electrical System (WT.GRP.300) (tons)	8.6	16.2	22.7	32.9
Command & Control (WT.GRP.400) (tons)	11.4	43.2	59.1	67.5
Aux. Systems (WT.GRP.5XX) (tons)	17.2	46.0	91.5	165.0
Foil Systems (WT.GRP.567) (tons)	43.0	95.1	177.1	332.3
Outfit & Furn. (WT.GRP.600) (tons)	18.3	39.1	72.9	123.5
Armament (WT.GRP.700) (tons)	9.5	12.4	22.0	75.6
Margins (tons)	28.6	61.7	109.1	191.9
Light Ship (tons)	219.0	473.2	836.4	1471.6
Fuel (tons)	74.5	189.3	365.2	788.1
Full Loads (tons)	20.4	25.7	80.3	165.8
Full Load Displacement (tons)	313.9	688.2	1281.9	2425.5

(2) Input the desired perturbation. e.g. add 10 tons to the armament item weight array.

NOTE: The Initialization section of HANDE is not sensitive to payload weight location. Payload weights are located at a constant height of 1.28 X hull's midship depth.

(3) Run the Initialization module and note the required volume.

(4) Using the Hull Geometry module, resize the reference ship hull to match the required volume found in the previous step.

(5) Rerun the Initialization module with the hull size set equal to that found in step 4.

(6) Record the weights and physical characteristics of the new design.

The above procedure was repeated for positive and negative perturbations of payload weight and enlisted crew size for each of the four baseline hydrofoils. HANDE is sensitive to distinctions between officers, chief petty officers, and enlisted crew but it was decided to investigate only the latter since the enlisted crew would be the most likely group to vary with payload size.

Since HANDE does not provide for the size of the electrical plant as an input, it is not possible to use the model directly to calculate marginal weight factors for electric load variations. Instead, a series

of hand calculations, derived from HANDE, was used to compute the required marginal factors. In the HANDE Initialization module group 300 weight will cause the ship to resize exactly as a group 700 weight does with the exception of the direct impact on KW by group 700. A sample calculation is shown in figure 3.1a.

The marginal weight factors for space were determined with the aid of the Hull Geometry module of the HANDE Synthesis section. As described earlier, this module resizes the hull and deckhouse as controlled by the program's user. An example illustrating space perturbations to a single baseline hydrofoil follows:

(1) Use the Hull Geometry module of HANDE to vary the internal deck space of the baseline ship. The hull's ratios such as L/B and L/D remain constant.

(2) Run the Initialization section with the hull size fixed equal to that determined in step 1.

(3) Record the weights and physical characteristics of the new design.

DIRECT WEIGHT IMPACT:

$WT.GRP.300 = 0.02 \times KW = 0.02 \times 100$ (Reference 7)

$WT.GRP.300 = 2.0$ tons

HP_{elo} = Electrical System Design Horsepower

$HP_{elo} = KW/(2 \times 0.98 \times 0.746) = 100/(2 \times 0.98 \times 0.746)$

$HP_{elo} = 68.4$ HP

HP_{el} = Average Electrical Plant Horsepower

$HP_{el} = 0.333\ HP_{elo} = 0.333 \times 68.4$

$HP_{el} = 22.8$ HP

W_{el} = Fuel Flow Rate $= 0.0762 HP_{elo} + 0.327 HP_{el}$

W_{el} 12.7 lbs/hr

WF_{40} = Weight of Fuel

$$WF_{40} = 1.02 \times \frac{RANGE \times W_{el}}{2240 \times SPEED} = \frac{2500 \times 12.7}{2240 \times 44}$$

$WF_{40} = 0.32$ tons

TOTAL DIRECT WEIGHT IMPACT = $WT.GRP.300 + WF_{40}$

= 2.32 tons

INDIRECT WEIGHT IMPACT:

Impact of 1.09 tons of direct weight gives as indirect weight impact of 1.72 tons. (Determined from HANDE WT.GRP.700 Initialization runs)

Therefore, INDIRECT IMPACT = 1.58 X DIRECT IMPACT

= 3.66 tons

Sample Calculation for Marginal Weight Factor for Electrical Load on 120BL.

Figure 3.1a

TOTAL WEIGHT IMPACT = DIRECT IMPACT + INDIRECT IMPACT

$$= 2.32 + 3.66$$

$$= 5.98 \text{ tons}$$

Marginal Weight Factor for a unit KW change to the 120BL hydrofoil's Electrical Load:

$$\frac{5.98 \text{ tons}}{100 \text{ KW}} = 0.0598 \text{ tons/KW}$$

Sample Calculation for Marginal Weight Factor for Electrical Load on 120BL

Figure 3.1a (Continued)

RESULTS

The results of the perturbations for the 120BL hydrofoil are presented in Tables 3.3, 3.4, 3.5, and 3.6. Results for the other three baselines may be found in Appendix II. The data was generated as described in the preceeding section of this chapter. Figures 3.2, 3.3, 3.4, and 3.5 were constructed by plotting the change in full load displacement versus the corresponding change in a support parameter. These figures help to illustrate the linearity of the variations, the relative magnitudes of the various weight groups' variations, and the absolute magnitude of the results of the perturbations. The slopes of these plots are, by definition, the marginal weight factors for the corresponding support parameter.

The marginal weight factors for each of the four baseline hydrofoils are shown in Tables 3.7, 3.8, 3.9, and 3.10. The bottom row of each of the tables contains the marginal weight factor for the 240BL ship as generated by the Synthesis section. Note that the results do verify the large error determined (see Appendix II) in the cargo weight variations used to test the Initialization section.

Figures 3.6, 3.7, 3.8, and 3.9 are plots of the full load marginal weight factors versus the corresponding displacement for the baseline hydrofoils. These figures illustrate the trends of marginal weight factors to increase with increasing displacement. In an attempt to further establish the validity of the data, two actual U. S. Navy Hydrofoil designs (PHM and HOC) were used with the HANDE Initialization

Table 3.3

Payload Weight Variations for 120BL Hydrofoil

	BASELINE	- 20 TONS		- 10 TONS		+ 10 TONS		+ 20 TONS	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF	NEW	DIFF	NEW	DIFF
LBP	222.7	221.6	- 1.1	222.3	- 0.4	223.1	+ 0.4	223.5	+ 0.8
FULL LOAD DISP.	1281.9	1222.7	- 59.2	1253.3	- 28.6	1310.2	+ 28.3	1338.4	+ 56.5
WT.GRP.100	191.3	188.6	- 2.7	190.2	- 1.1	192.3	+ 1.0	193.4	+ 2.1
WT.GRP.200	90.8	87.4	- 3.4	89.2	- 1.6	92.3	+ 1.5	93.9	+ 3.1
WT.GRP.300	22.7	20.9	- 1.8	21.8	- 0.9	23.6	+ 1.1	24.4	+ 1.7
WT.GRP.400	59.1	59.0	- 0.1	59.1	0.0	59.1	0.0	59.2	+ 0.1
WT.GRP.5XX	91.5	90.6	- 0.9	91.1	- 0.4	91.8	+ 0.3	92.2	+ 0.7
WT.GRP.567	177.1	168.9	- 8.2	173.1	- 4.0	180.9	+ 3.8	184.8	+ 7.7
WT.GRP.600	72.9	72.2	- 0.7	72.6	- 0.3	73.1	+ 0.2	73.3	+ 0.4
WT.GRP.700	22.0	2.0	- 20.0	12.0	- 10.0	32.0	+ 10.0	42.0	+ 20.0
LIGHT SHIP	836.4	793.5	- 42.9	815.5	- 20.9	857.0	+ 20.6	877.6	+ 41.2
ACT.TOTAL VOL.	173925	171462	- 2463	172935	- 990	174847	+ 922	175788	+ 1863
REQ.TOTAL VOL.	173638	171216	- 2422	172470	- 1168	174786	+ 1148	175927	+ 2289
FUEL	365.2	349.2	- 16.0	357.4	- 7.8	372.8	+ 7.6	380.4	+ 15.2

Table 3.4

Enlisted Manning Variations for 120BL Hydrofoil

	BASELINE	- 10 MEN		- 5 MEN		+ 5 MEN		+ 10 MEN	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF	NEW	DIFF	NEW	DIFF
LBP	222.7	219.7	- 3.0	221.2	- 1.5	223.9	+ 1.2	225.1	+ 2.4
FULL LOAD DISP.	1281.9	1229.3	- 52.6	1255.6	- 26.3	1305.9	+ 24.0	1330.2	+ 48.3
WT.GRP.100	191.3	184.0	- 7.3	187.6	- 3.7	194.4	+ 3.1	197.5	+ 6.2
WT.GRP.200	90.8	88.0	- 2.8	89.4	- 1.4	92.0	+ 1.2	93.3	+ 2.5
WT.GRP.300	22.7	22.1	- 0.6	22.4	- 0.3	23.0	+ 0.3	23.3	+ 0.6
WT.GRP.400	59.1	58.9	- 0.2	59.0	- 0.1	59.2	+ 0.1	59.3	+ 0.2
WT.GRP.5XX	91.5	84.7	- 6.8	88.1	- 3.4	94.7	+ 3.2	97.9	+ 6.4
WT.GRP.567	177.1	169.9	- 7.2	173.5	- 3.6	180.3	+ 3.2	183.7	+ 6.6
WT.GRP.600	72.9	67.6	- 5.3	70.2	- 2.7	75.3	+ 2.4	77.8	+ 4.9
WT.GRP.700	22.0	22.0	0.0	22.0	0.0	22.0	0.0	22.0	0.0
LIGHT SHIP	836.4	801.6	- 34.8	819.0	- 17.4	852.1	+ 15.7	867.9	+ 31.5
ACT.TOTAL VOL.	173925	167238	- 6687	170579	- 3346	176686	+ 2761	179509	+ 5584
REQ.TOTAL VOL.	173638	167430	- 6208	170546	- 3092	176618	+ 2980	179588	+ 5950
FUEL	365.2	351.1	- 14.1	358.2	- 7.0	371.6	+ 6.4	378.0	+ 12.8

Table 3.5

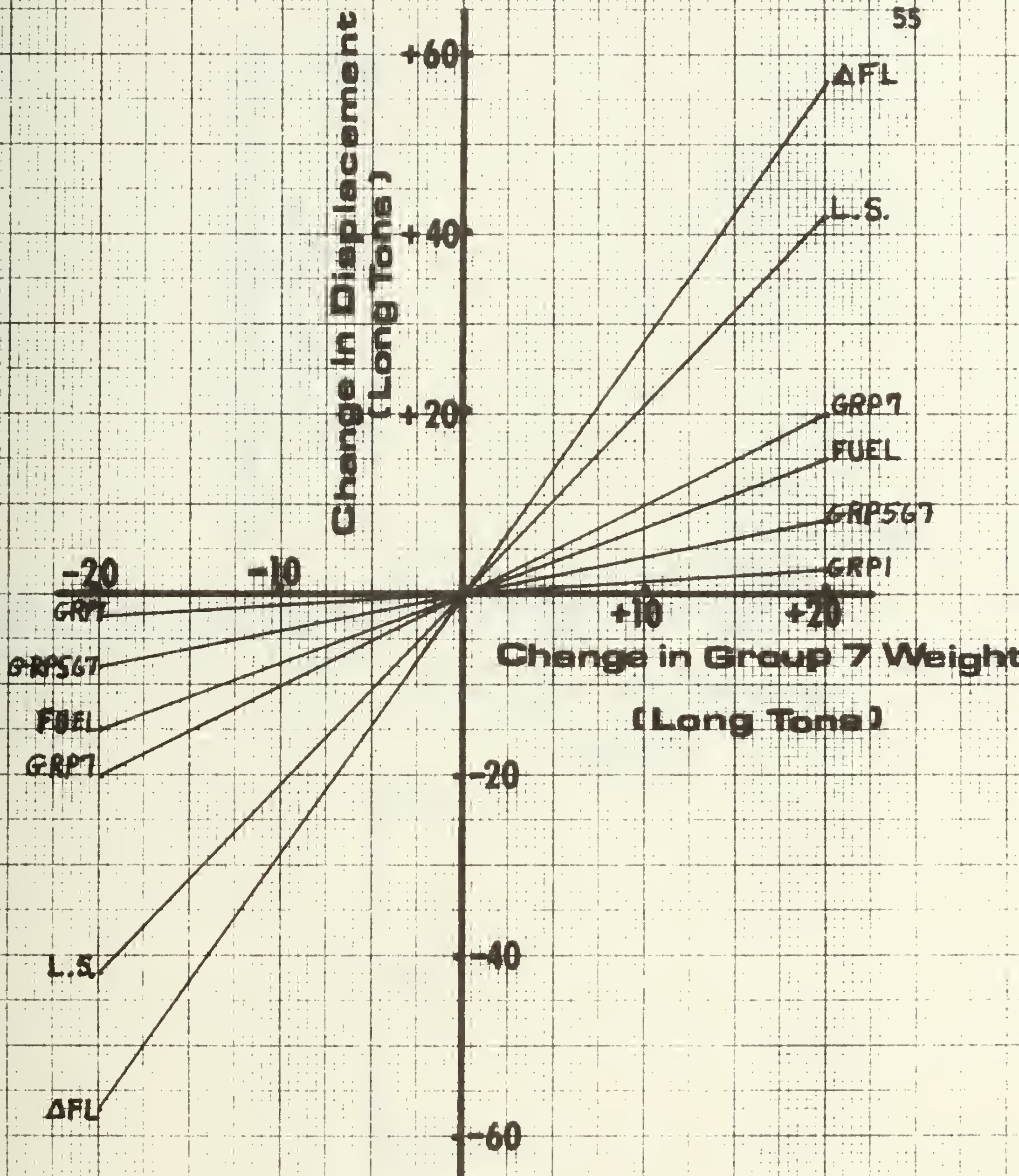
Electrical Power Variations for 120BL Hydrofoil

	BASELINE	+ 250 KW		+ 500 KW	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF
LBP	222.7	222.9	+ 0.2	223.1	+ 0.4
FULL LOAD DISP.	1281.9	1296.9	+ 15.0	1311.9	+ 30.0
WT.GRP.100	191.3	191.9	+ 0.6	192.5	+ 1.2
WT.GRP.200	90.8	91.6	+ 0.8	92.4	+ 1.6
WT.GRP.300	22.7	27.8	+ 5.1	32.9	+ 10.2
WT.GRP.400	59.1	59.1	0.0	59.2	+ 0.1
WT.GRP.5XX	91.5	91.7	+ 0.2	91.9	+ 0.4
WT.GRP.567	177.1	179.1	+ 2.0	181.1	+ 4.0
WT.GRP.600	72.9	73.0	+ 0.1	73.1	+ 0.2
WT.GRP.700	22.0	22.0	0.0	22.0	0.0
LIGHT SHIP	836.4	846.7	+ 10.3	857.0	+ 20.6
ACT.TOTAL VOL.	173925	174469	+ 545	175015	+ 1090
FUEL	365.2	369.9	+ 4.7	374.6	+ 9.4
KW	1135	1390	+ 255	1645	+ 510

Table 3.6

Space Variation for 120RL Hydrofoil

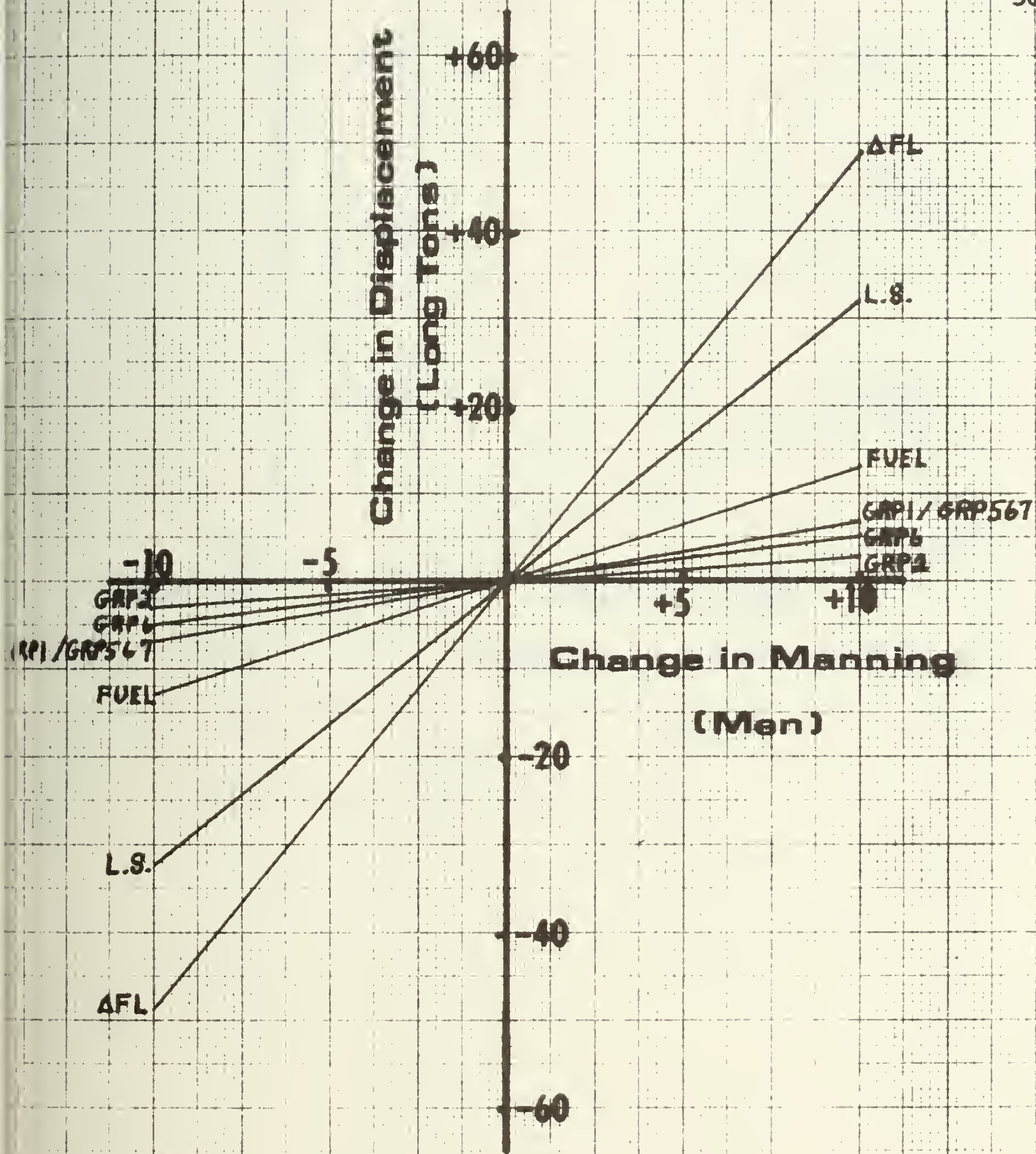
	BASELINE	+ 86 FT^2		+ 315.5 FT^2		+ 663 FT^2	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF	NEW	DIFF
LBP	222.7	223.0	+ 0.3	223.8	+ 1.1	225.0	+ 2.3
FULL LOAD DISP.	1281.9	1284.6	+ 2.7	1291.9	+ 10.0	1302.8	+ 20.9
WT.GRP.100	191.3	192.1	+ 0.8	194.1	+ 2.8	197.2	+ 5.9
WT.GRP.200	90.8	90.9	+ 0.1	91.2	+ 0.4	91.9	+ 1.1
WT.GRP.300	22.7	22.7	0.0	22.8	+ 0.1	22.9	+ 0.2
WT.GRP.400	59.1	59.1	0.0	59.2	+ 0.1	59.3	+ 0.2
WT.GRP.5XX	91.5	91.7	+ 0.2	92.4	+ 0.9	93.5	+ 2.0
WT.GRP.567	177.1	177.4	+ 0.3	178.4	+ 1.3	179.6	+ 2.5
WT.GRP.600	72.9	73.0	+ 0.1	73.5	+ 0.6	74.2	+ 1.3
WT.GRP.700	22.0	22.0	0.0	22.0	0.0	22.0	0.0
LIGHT SHIP	836.4	838.4	+ 2.0	843.7	+ 7.3	851.7	+ 15.3
ACT.TOTAL VOL.	173925	174613	+ 688	176449	+ 2524	179228	+ 5304
FUEL	365.2	365.9	+ 0.7	367.8	+ 2.6	370.8	+ 5.6



120BL

Change in Full Load Displacement
VS
Change in Payload Weight

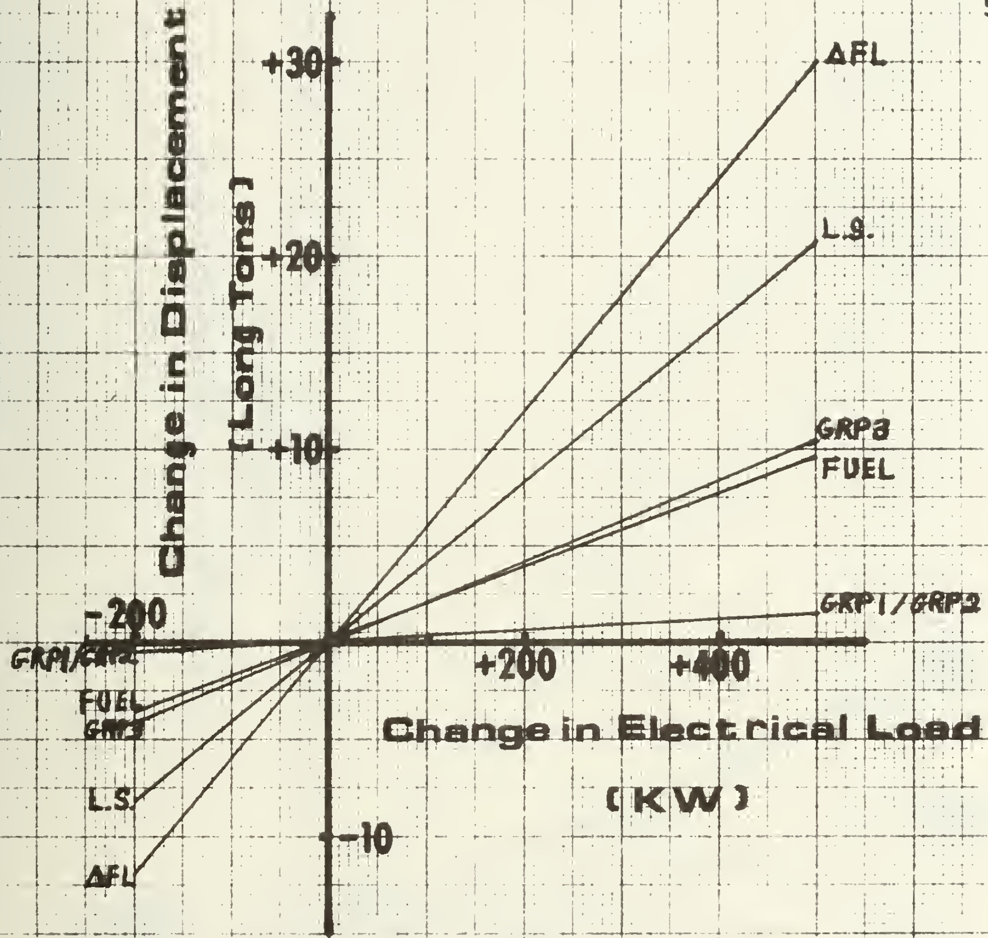
Figure 3.2



120BL

Change in Full Load Displacement
VS
Change in Enlisted Manning

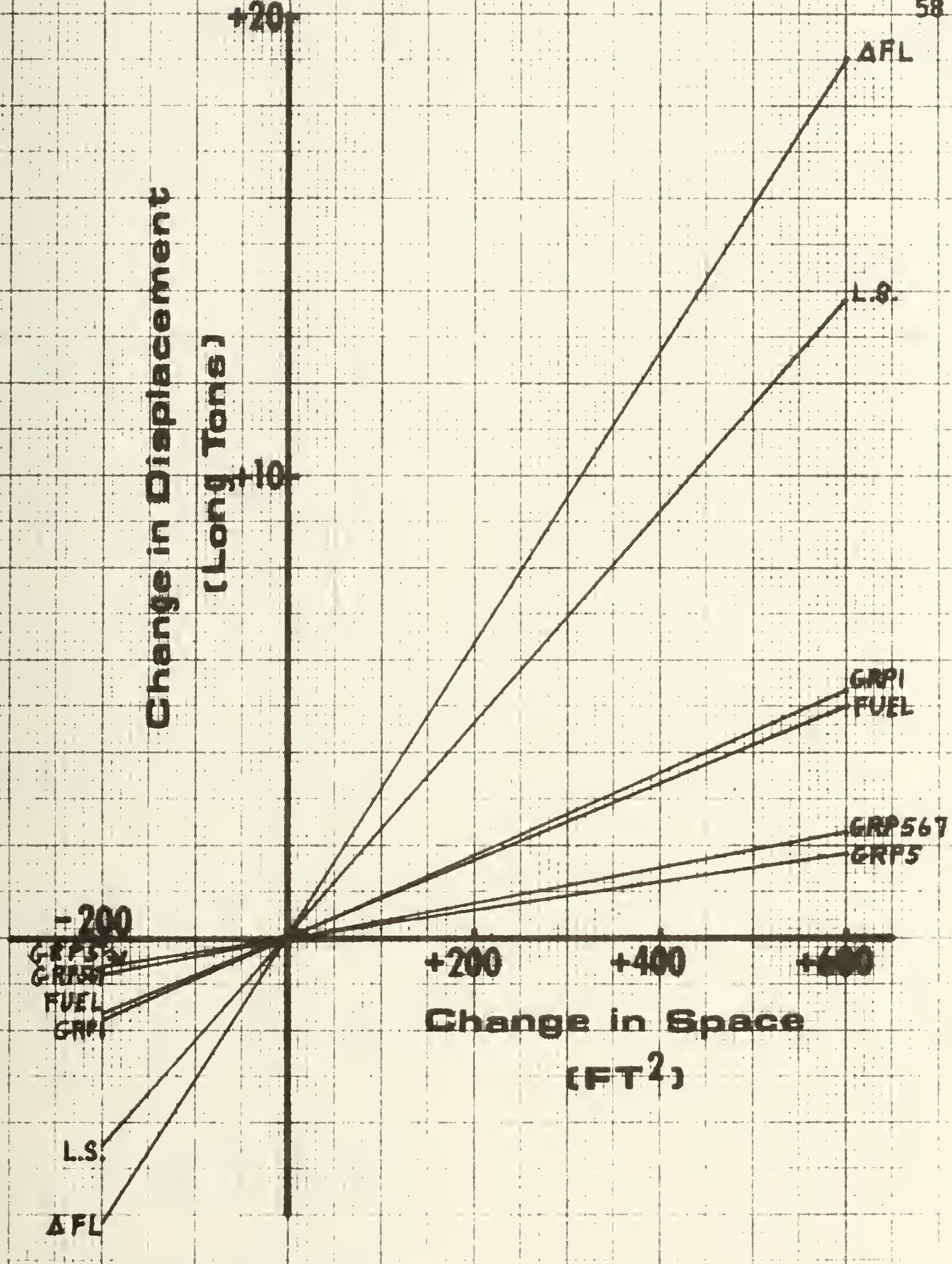
Figure 3.3



120BL

Change in Full Load Displacement
VS
Change in Electrical Load

Figure 3.4



120BL

Change in Full Load Displacement
VS
Change in Space

Figure 3.5

Table 3.7

Hydrofoil Marginal Weight Factors for Weight Variation

BASELINE SHIP	Δ FL	L.S.	GRP7	FUEL	GRP567	GRP1
INITIAL. - 30BL	3.20	2.45	1.0	0.74	0.44	0.18
INITIAL. - 60BL	2.80	1.93	1.0	0.47	0.24	0.13
INITIAL. - 120BL	2.85	2.10	1.0	0.76	0.38	0.10
INITIAL. - 240BL	2.90	2.07	1.0	0.82	0.37	0.14
SYNTHESIS - 240BL	4.90	3.32	1.0	1.58	0.80	0.34

Table 3.8

Hydrofoil Marginal Weight Factors for Fnlisted Manning Variation

BASELINE SHIP	Δ FL	L.S.	FUEL	GRP1	GRP567	GRP2	GRP6
INITIAL. - 30BL	6.35	4.54	1.44	0.72	0.85	0.50	0.64
INITIAL. - 60BL	4.80	3.19	1.25	0.61	0.66	0.30	0.50
INITIAL. - 120BL	5.05	3.31	1.34	0.68	0.68	0.26	0.51
INITIAL. - 240BL	5.03	3.14	1.47	0.62	0.66	0.22	0.50
SYNTHESIS - 240BL	7.20	4.49	2.10	0.89	0.94	0.31	0.72

Table 3.9

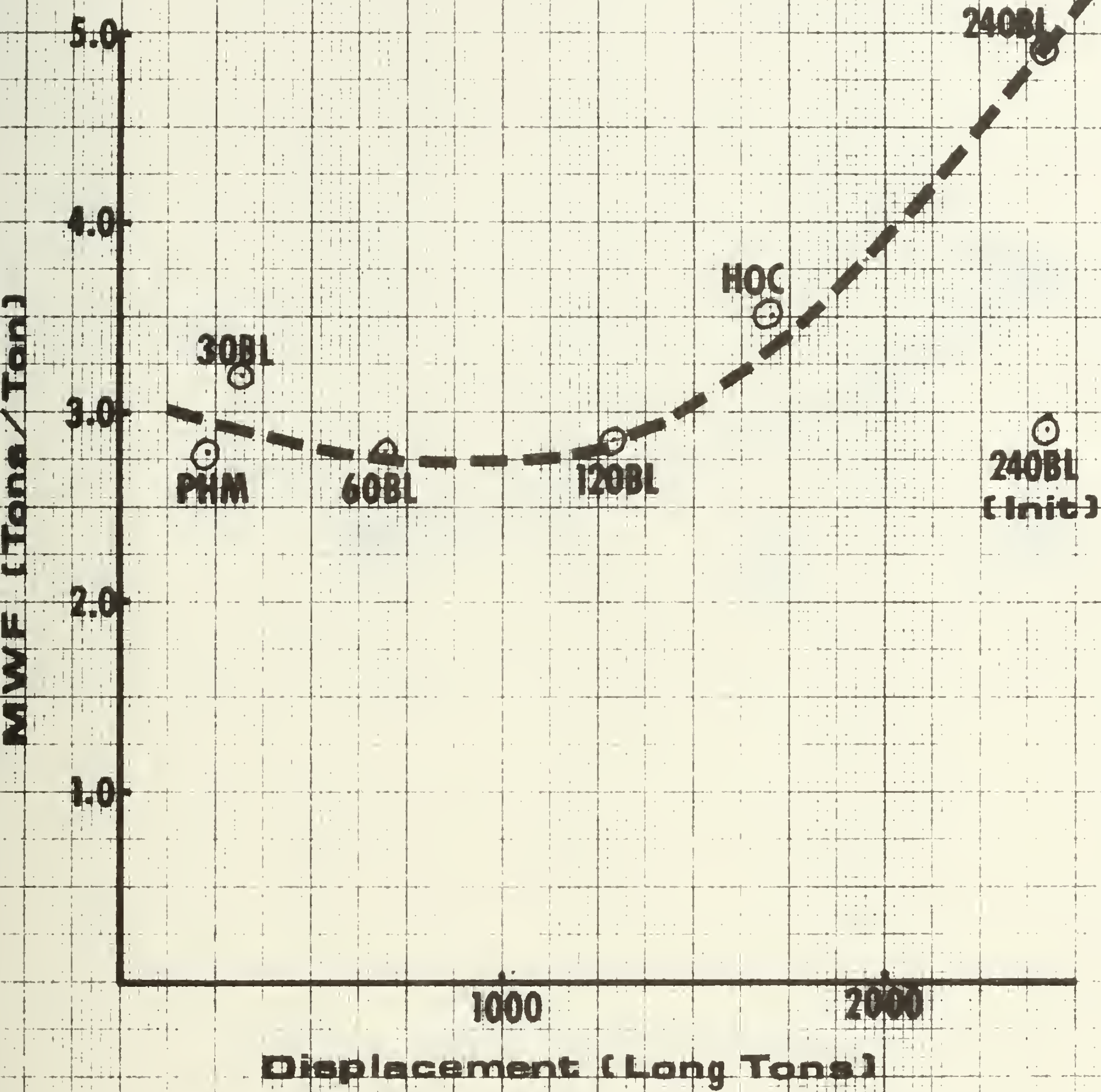
Hydrofoil Marginal Weight Factors for Electrical Load Variation

BASELINE SHIP	Δ FL	L.S.	GRP3	FUEL	GRP567
INITIAL. - 30BL	0.047	0.04	0.020	0.006	0.002
INITIAL. - 60BL	0.035	0.03	0.020	0.005	0.002
INITIAL. - 120BL	0.060	0.04	0.020	0.019	0.008
INITIAL. - 240BL	0.061	0.05	0.020	0.016	0.009
SYNTHESIS - 240BL	0.091	0.08	0.021	0.011	0.011

Table 3.10

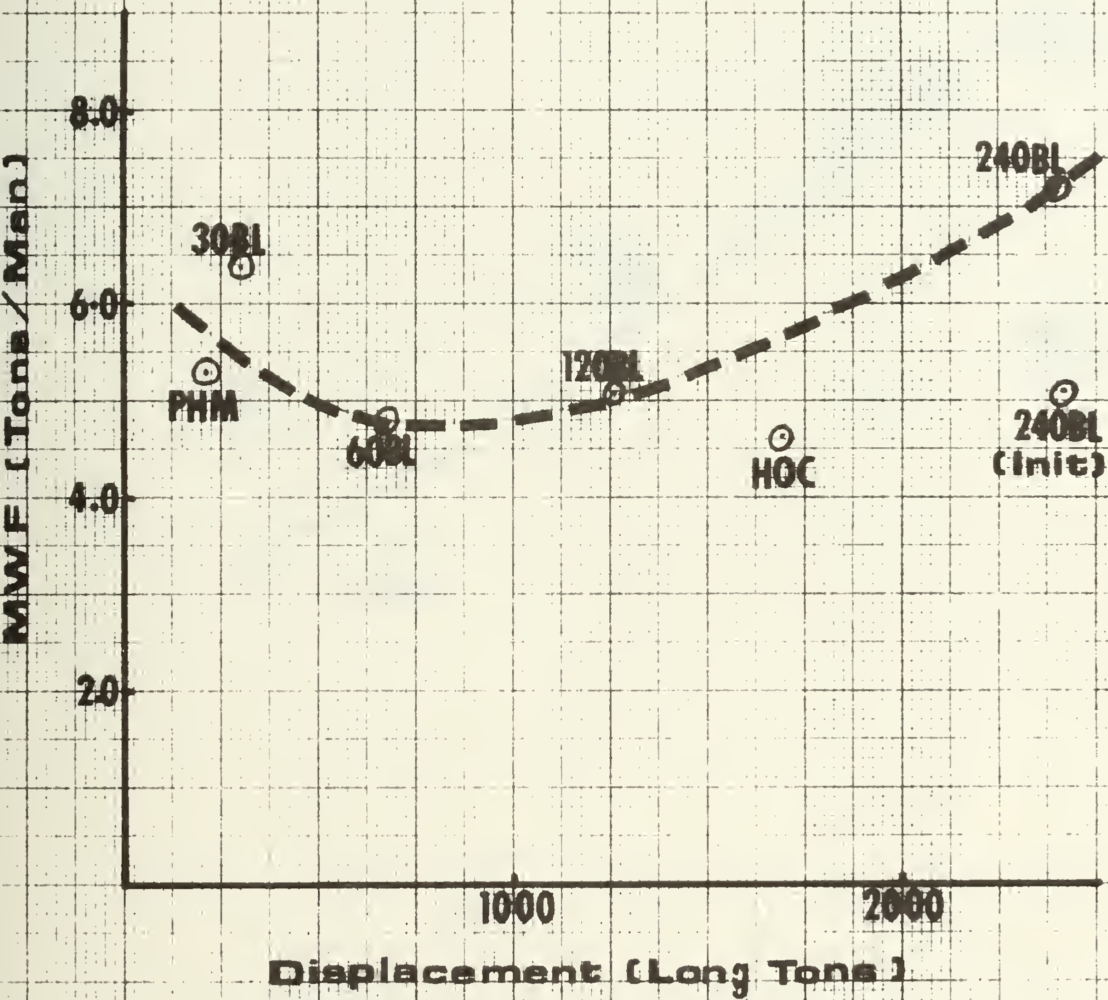
Hydrofoil Marginal Weight Factors for Space Variation

BASELINE SHIP	Δ FL	L.S.	FUEL	GRP1	GRP567	GRP2
INITIAL. - 30BL	0.031	0.024	0.007	0.009	0.004	0.003
INITIAL. - 60BL	0.029	0.021	0.008	0.009	0.004	0.002
INITIAL. - 120BL	0.032	0.023	0.008	0.009	0.004	0.001
INITIAL. - 240BL	0.033	0.023	0.010	0.009	0.004	0.002
SYNTHESIS - 240BL	0.050	0.035	0.015	0.014	0.006	0.004



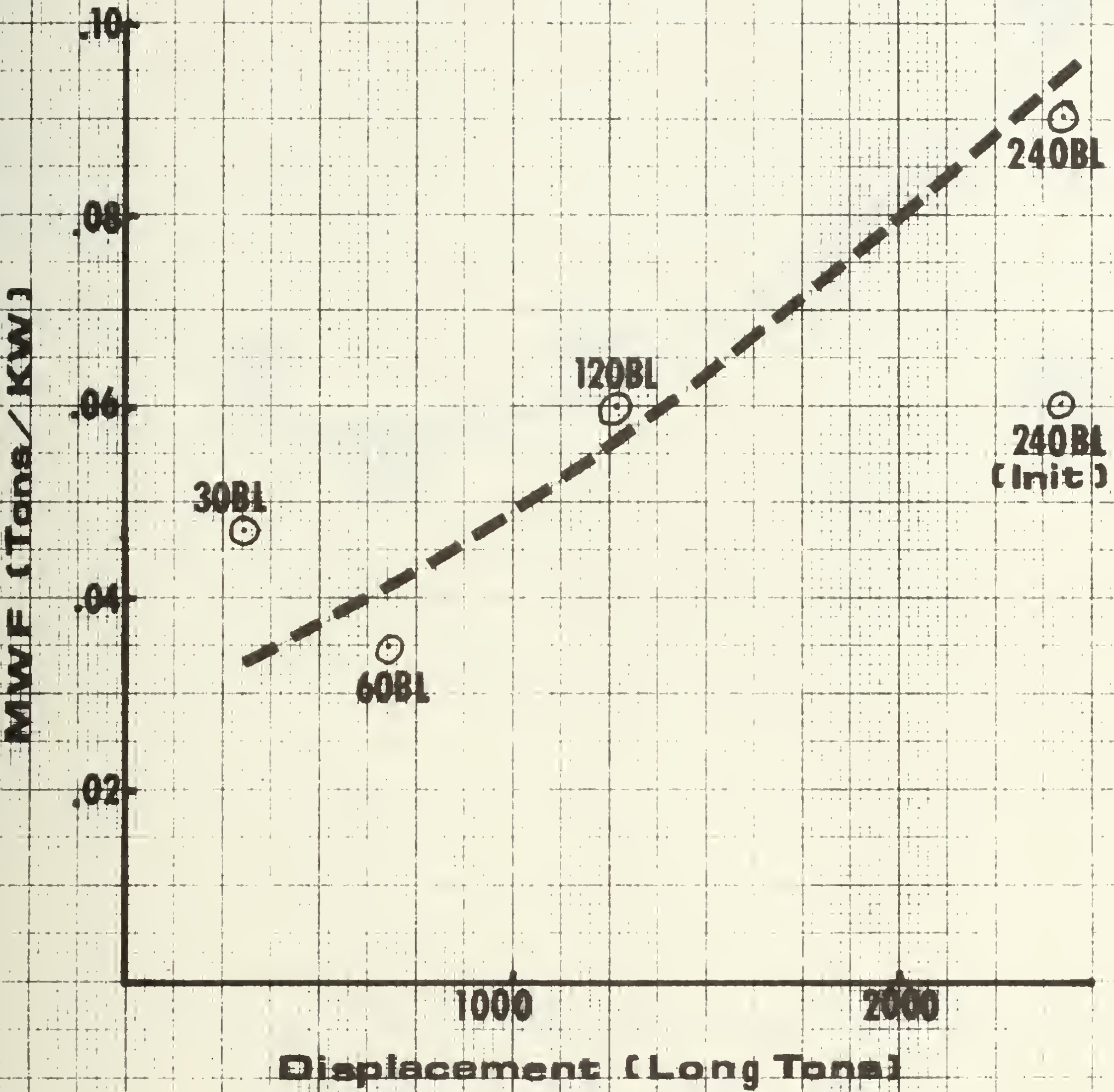
MWF For Payload Weight
VS
Full Load Displacement

Figure 3.6



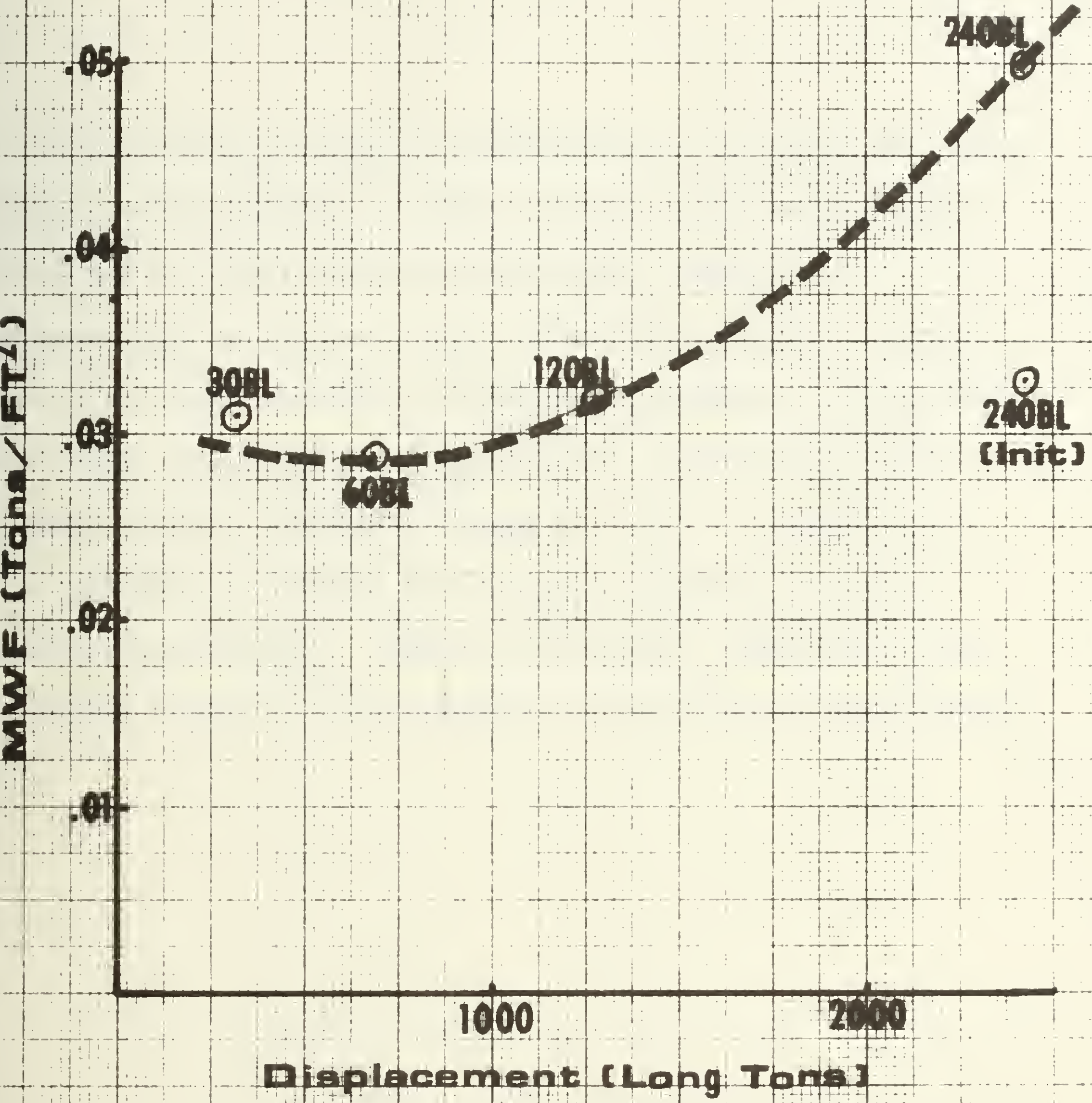
MWF For Enlisted Manning
VS
Full Load Displacement

Figure 3.7



MWF For Electrical Load
VS
Full Load Displacement

Figure 3.8



MWF For Space
VS
Full Load Displacement

Figure 3.9

module. Marginal weight factors for payload weight and enlisted manning perturbations were calculated as before and the results are plotted in Figures 3.6 and 3.7 along with the four original baselines.

Synthesis runs for payload weight and enlisted manning variations were made on the 240BL hydrofoil to determine the degree of inaccuracy in Initialization for large displacement ships. The marginal weight factors found are also plotted in Figures 3.6, 3.7, 3.8, and 3.9. To assist in investigating reasons for the large discrepency between Initialization and Synthesis, Figure 3.10 presents a comparison of the marginal weight factors for each component of the full load displacement factor.

	SYNTHESIS MWF	INITIALIZATION MWF
FULL LOAD DISPLACEMENT	4.90	2.90
WT.GRP.100	0.34	0.14
WT.GRP.200	0.56	0.13
WT.GRP.300	0.07	0.07
WT.GRP.400	0.005	0.008
WT.GRP.5XX	0.08	0.05
WT.GRP.567	0.80	0.37
WT.GRP.600	0.04	0.03
WT.GRP.700	1.00	1.00
LIGHT SHIP	3.32	2.07
FB SHP	185.9	87.8

Figure 3.10 - Comparison of Marginal Weight Factors for 240BL Payload Weight Variations as Generated by the Synthesis and Initialization sections of HANDE.

ISCUSSION OF RESULTS

The results indicate that marginal weight factors for hydrofoils end to increase for all four payload support parameters as full load isplacement increases. Both the Navy's PHM and the (NAVSEC) HOC esigns also follow the trends established by the four baselines. Three actors are thought to account for the general trend of increasing WF's with increasing ship size. First, the structural efficiency of the oil system degrades for the heavier hydrofoils thus increasing the foil eight more for the larger ships; secondly, fuel consumption grows at a roportionally larger rate on the heavier vessels thus significantly aising the fuel weight; and finally, the baselines have increasing ange requirements as the displacement increases thus also increasing ne fuel weight more for larger ships.

The results for the smallest hydrofoil (30BL) are somewhat larger nan was expected. Although an exact reason for these higher MWF's is not able to be determined, it is felt that small errors in the data in make a more significant impact on the size of the MWF's of smaller ips.

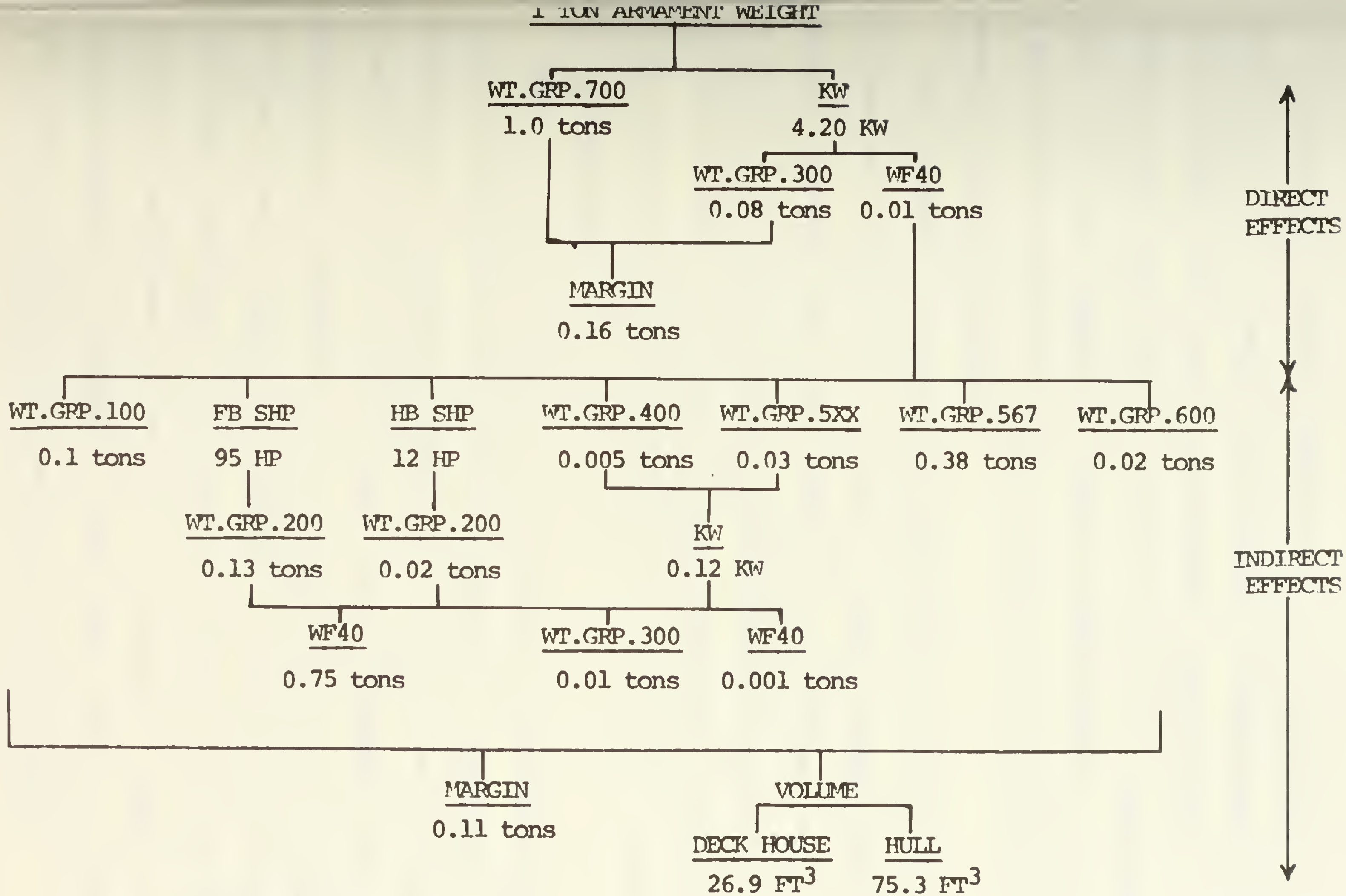
The size of the marginal weight factors produced using the HANDE del is strongly affected by the degree of balancing of required and ailable volumes. For example, if the 120BL is designed such that the lume available exceeds the volume required by 16,000 FT^3 (an error 9%), a marginal weight factor for payload weight variation on the

120BL hydrofoil of 5.2 results vice the 2.85 for a volume balanced design.

Figure 3.10 illustrates several problem areas noted when using the Initialization module of HANDE for large hydrofoil designs. The source of error is that Initialization underestimates the size of the foil system selected which in turn underestimates the hydrodynamic drag. This error is reflected in the size of weight group 200, foilborne shaft horsepower, and weight group 567. The error in weight group 100 results from a larger ship being required to carry the additional fuel and increased propulsion plant weight.

As can be seen in Figures 3.2, 3.3, 3.4, 3.5 marginal weight factors produced by Initialization are linear. These results are to be expected as the various weight estimating relationships of HANDE are generally linear equations. Minor exceptions are not of sufficient size to generate non-linear results.

The payload weight perturbations were linear for all displacements and sizes of perturbations investigated. A breakdown of the payload weight marginal factor is shown in Figure 3.11. The figure illustrates how the one ton change in armament weight affects a hydrofoil. The effects are separated into two groups: Direct effects and Indirect effects. Direct effects reflect the expected impact of the change in armament weight; whereas the indirect effects are the growth in the hydrofoil produced as the HANDE model iterates the design to account for the direct effects.



DIRECT WEIGHTS = 1.24 tons
INDIRECT WEIGHTS = 1.56 tons
TOTAL WEIGHT IMPACT = 2.80 tons

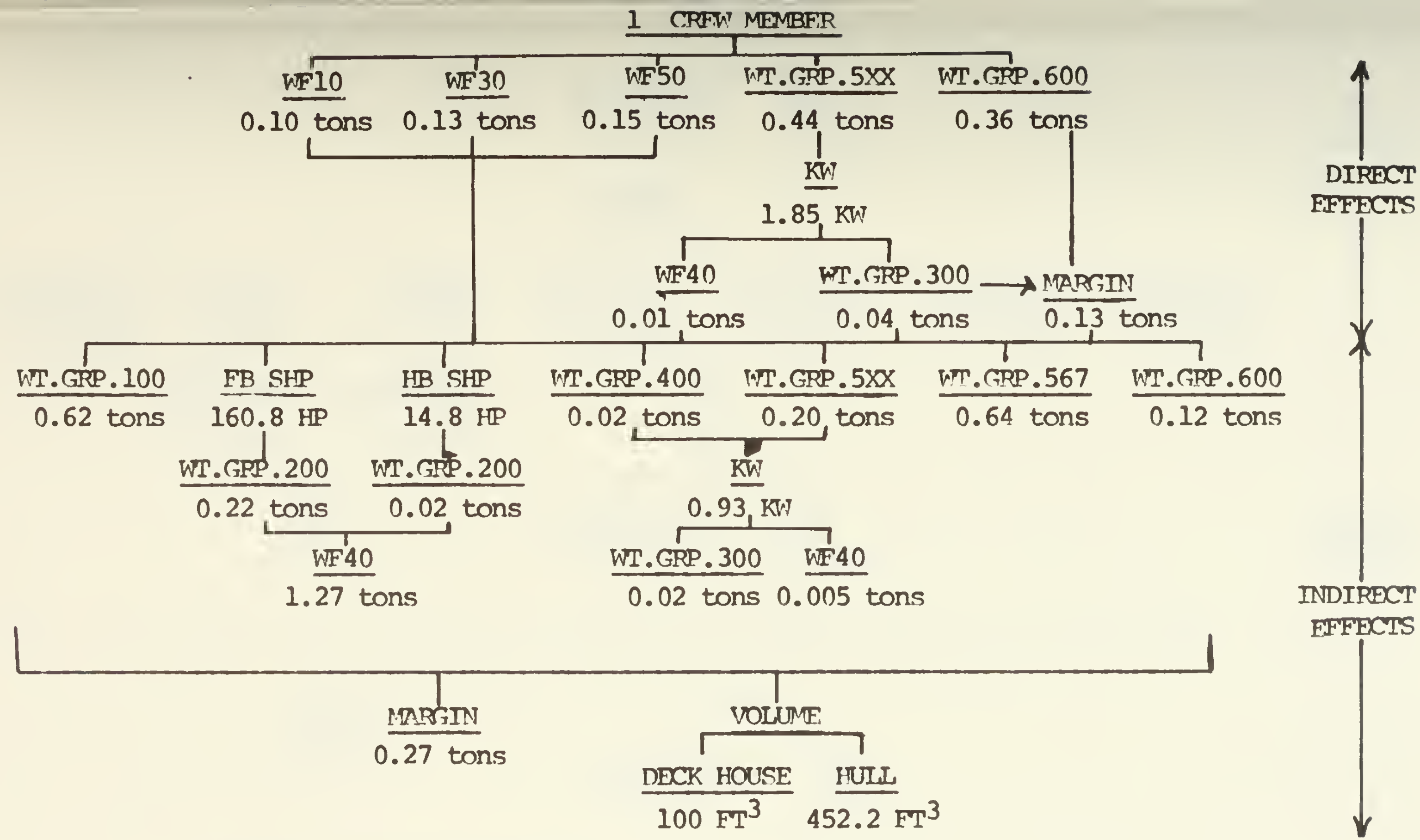
TOTAL VOLUME IMPACT = 102.2 FT^3

Figure 3.11 - Breakdown of MWF for addition of 1 ton of Payload Weight to WT.GRP.700 on 120BL

Payload weight directly impacts the size of weight group 700, weight group 300, the margin (15% of the sum of weight groups 100 - 700), and the weight of the fuel for the increased electrical plant. In contrast, cargo weight added to a hydrofoil produces a smaller marginal weight factor (see Appendix II) since the direct effects are much smaller as the cargo weight does not require a direct increase in electrical load or the margin.

The breakdown for the marginal weight factor for enlisted manning is presented in Figure 3.12. A change in manning produces direct effects on the full load items of water, crew and effects, and provisions in addition to increasing weight groups 5XX and 600. The size of the factors for the HOC is slightly lower than expected and may be due to a smaller weight margin factor (0.13 for HOC versus 0.15 for the baselines).

Figures 3.13 and 3.14 present breakdowns for the marginal weight factors for electrical load and space respectively. Because hand calculations are involved in computing these marginal weight factors, the breakdowns for the indirect effects are not considered to be as reliable as those produced for payload weight and enlisted manning. The direct effects, however, are accurate and reflect the true impact of the support parameters. The value of the marginal weight factor for the full load change is considered to be accurate; however, the breakdown shown for the individual weight groups, normally produced by the computer's iteration, represents only an approximation.

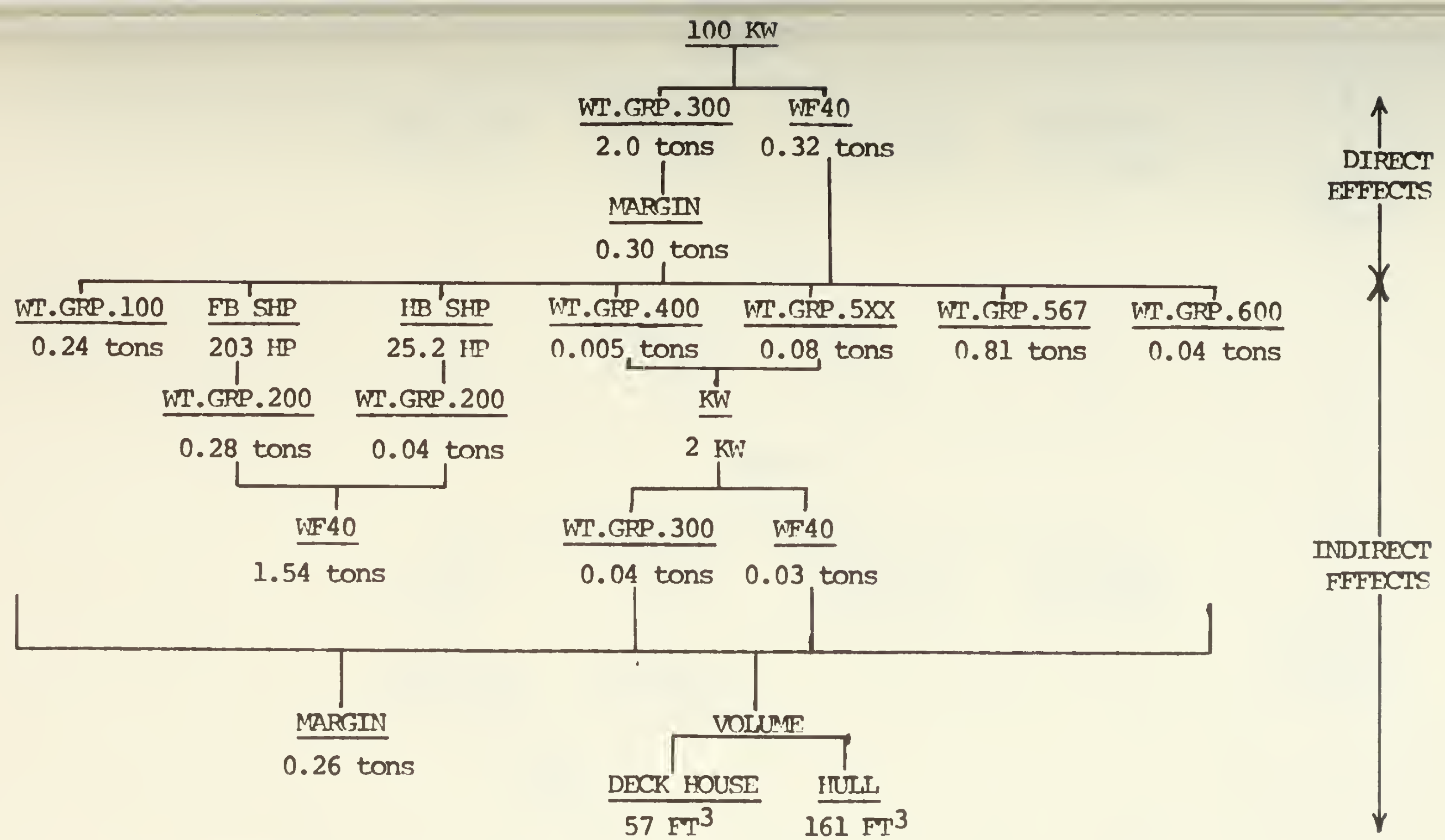


DIRECT WEIGHTS = 1.36 tons
INDIRECT WEIGHTS = 3.44 tons

TOTAL WEIGHT IMPACT = 4.80 tons

TOTAL VOLUME IMPACT = 552.2 FT^3

Figure 3.12 - Breakdown of MWF for addition of 1 Man to 120 RL

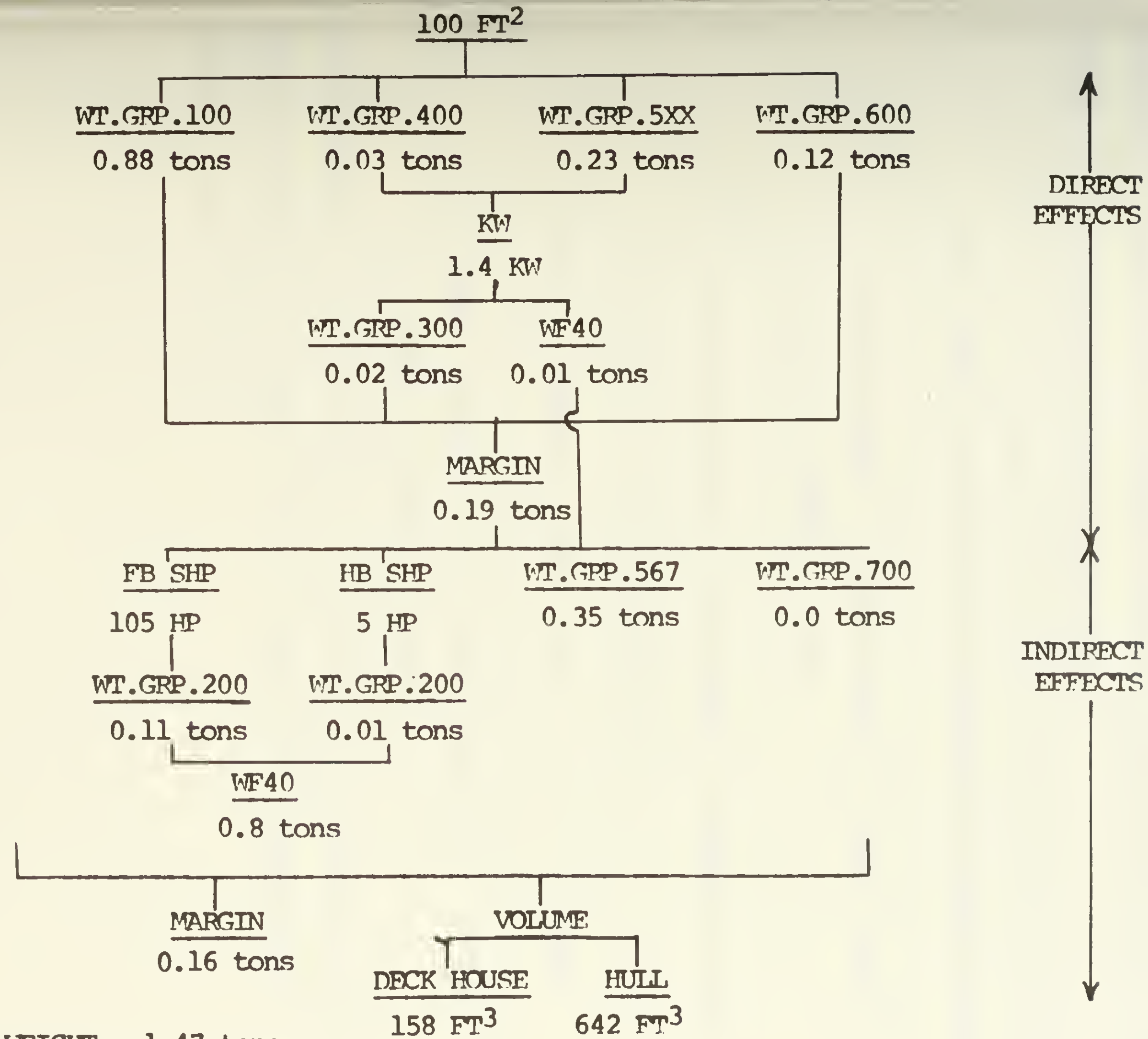


DIRECT WEIGHTS = 2.62 tons
INDIRECT WEIGHTS = 3.36 tons

TOTAL WEIGHT IMPACT = 5.98 tons

TOTAL VOLUME IMPACT = 218 FT^3

Figure 3.13 - Breakdown of MWF for addition of 100 KW to Electrical Load of 120BL



DIRECT WEIGHT = 1.47 tons
INDIRECT WEIGHT = 1.73 tons
TOTAL WEIGHT IMPACT = 3.20 tons

TOTAL VOLUME IMPACT = 800 FT^3

Figure 3.14 - Breakdown of MWF for addition of 100 FT^2 to required space on 120BL

To demonstrate the ability to determine the total impact of a subsystem by summing the individual effects predicted by marginal weight factors, the following procedure was followed.

(1) Run the Initialization module with perturbations of +15 tons payload weight and +3 enlisted men entered simultaneously.

(2) Using the marginal weight factor for payload weight, predict the impact of adding 15 tons.

(3) Using the marginal weight factor for manning, predict the impact of adding 3 enlisted men.

(4) Sum the results found in steps (2) and (3) above.

(5) Compare the predicted result determined in step(4) with the output generated in step (1).

The comparison is shown in Table 3.11 and the predicted and actual weight changes differ by less than 2% which is within the Initialization module's range of accuracy.

Table 3.11

Comparison of Predicted and Actual Weight Changes for Addition of 15 tons Payload Weight and 3 Men to 120BL Hydrofoil.

	MWF Weight	Weight Impact	MWF Manning	Manning Impact	Total Predicted Impact	Actual HANDF Impact
FULL LOAD DISP.	2.85	+ 42.75	5.05	+ 15.15	+ 57.9	+ 56.8
WT.GRP.100	0.11	+ 1.65	0.68	+ 2.04	+ 3.7	+ 3.4
WT.GRP.200	0.15	+ 2.25	0.26	+ 0.78	+ 3.0	+ 3.1
WT.GRP.300	0.11	+ 1.65	0.06	+ 0.18	+ 1.8	+ 1.4
WT.GRP.400	0.005	+ 0.08	0.02	+ 0.06	+ 0.1	+ 0.1
WT.GRP.5XX	0.03	+ 0.45	0.66	+ 1.98	+ 2.4	+ 2.4
WT.GRP.567	0.38	+ 5.70	0.69	+ 2.07	+ 7.8	+ 7.7
WT.GRP.600	0.02	+ 0.30	0.51	+ 1.53	+ 1.9	+ 1.8
WT.GRP.700	1.00	+ 15.00	0.00	0.00	+ 15.0	+ 15.0
LIGHT SHIP	2.07	+ 31.05	3.32	+ 9.96	+ 41.0	+ 40.3
FUEL	0.76	+ 11.4	1.35	+ 4.05	+ 15.5	+ 15.3

CONCLUSIONS

(1) The Initialization module may be used for high level tradeoff studies to predict full load displacements with an accuracy of ± 5% for hydrofoils of less than 1500 tons displacement. The accuracy is reduced to ± 10% as full load displacement approaches 3000 tons.

(2) Initialization produces accurate marginal weight factors for hydrofoils of less than 1500 tons displacement. For larger hydrofoils, it is necessary to use the Synthesis section of HANDE to generate accurate marginal weight factors.

(3) All perturbations investigated, produced linear changes to the full load displacements of all baseline hydrofoils. Non-linear results may be expected when investigating large hydrofoils with the Synthesis section.

(4) Although HANDE does not converge the design with respect to volume, it is important to do so manually to produce accurate marginal weight factors.

(5) A general trend of increasing marginal weight factors with increasing displacement for all four payload support parameters is noted. This trend is due to the heavier foil systems, increased operating range requirements, and an increasing fuel consumption on the larger hydrofoils.

CHAPTER 4.

MARGINAL WEIGHT FACTORS FOR SURFACE EFFECT SHIPS

INTRODUCTION

This chapter discusses the generation of marginal weight factors for Surface Effect Ships (SES) the four payload support areas of weight, manning, electrical power, and space. The factors were computed with the aid of a ship synthesis model developed by Mr. William Richardson of the David Taylor Naval Ship Research and Development Center (DTNSRDC). This model solves for a minimum weight ship subject to performance constraints specified by the user.

Surface Effect Ships encorporate a technology that significantly reduces hydrodynamic drag and allows much higher speeds than conventional displacement ships. The air cushion vehicles, developed primarily in Great Britian, are the forerunners of the Surface Effect Ship. Air cushion craft as large as 220 tons are being utilized in both commercial and military service in the United Kingdom and the Soviet Union. These vehicles employ a cushion of air contained beneath a flexible skirt and are normally propelled by air screw propellors driven by gas turbine engines. In contrast, SES technology encorporates rigid sidewalls, intergral to the hull structure, with flexible rubberized fabric seals fore and aft to contain the air cushion. The rigid sidewalls are narrow immersed hulls that provide additional stability at high speeds and allow the use of the more efficient waterjets or water propellers for propulsion.

While running in the on-cushion mode, the SES operates on a captured air bubble to reduce the hydrodynamic drag and achieve speeds in excess of 60 knots. In addition, while operating on-cushion, the SES can accelerate, decelerate, backdown, and hover. When the SES switches to the off-cushion mode, the vehicle operates as a conventional displacement ship with its weight supported by the buoyancy of the sidewalls.

ARCJ6 SES COMPUTER SHIP SYNTHESIS MODEL

To generate the marginal factors for SES's, the non-linear optimization program,developed by Mr. Richardson of DTNSRDC, was utilized. This program, known as ARCJ6, was developed in 1969 for the Trident submarine project and revised in 1976. It uses SES parametric relationships to solve for a minimum weight ship subject to various naval architectural and performance constraints. The program's feature of being able to specify performance requirements and have the ship's displacement as an output, led to the selection of ARCJ6 for use in this thesis.

The program requires that the user set up a data base describing the ship. This data base consists of various functional relationships, known constants, performance constraints, and naval architectural requirements. Examples of the performance specifications are a required cruise and dash speed, payload weight, and the SES's range. The naval architectural requirements include the requirements that buoyancy equals weight or that reasonable trim and stability be maintained. The program is non-specific as to ship type. That is to say, the user must specify

the vehicle's description. Once the program has the ship's description, it proceeds to use the data base to form and solve the optimization equations.

The program is similiar to HANDE (the hydrofoil ship synthesis model) in that a volume balance is <u>not</u> performed. The SES is very weight sensitive and any increase in required volume requires a negligible increase in total ship weight. Therefore, although the program does not explicitly balance volume, sufficient internal volume can be designed into the ship through the use of appropriate weight estimating relationships.

There are four features to the ARCJ6 program which should be emphasized. They are:

(1) The level of detail generated by the model is directly controlled by the complexity and number of functional relationships that are input by the user.

(2) Because the description of forces acting on a ship is usually non-linear, the program was designed with the provision of handling non-linear variables.

(3) Since the user describes the ship via a set of functional relationships and the computer in turn produces a set of consistent descriptive values, it is not necessary that a parent or baseline ship be input to solve the optimization program.

(4) Finally, since the vehicle description and applicable physical and engineering relationships are input by the user, the ARCJ6 program consists of only three main section: One to recognize the data and check for internal consistency; a second section to perform the optimization; and, a third section that prints the output.

The ARCJ6 program performs the following functions in the order given:

(1) Interpret the vehicle description and functional relations thus building the data base to be used for the optimization run.

(2) Checks for inconsistencies and missing information among the elements of vehicle and physical data supplied by the user. The program does not contain any default values and the user must ensure that all required data has been specified.

(3) Prepares and prints tables illustrating what is in the data base and what are the applicable numerical values.

(4) Performs the weight minimization subject to the specified constraint equations. This is done by making use of a simultaneous non-linear equation solver that determines the numerical values of the variables which satisfy the set of simultaneous partial differential and algebraic equations. Prior to each iteration in the minimization

procedure, the program will check and adjuct the values of the variables to ensure consistency between the variables.

(5) Prepares and prints output tables including:

(a) Comparison between initial and final values of variables.

(b) Summary of items forming the current weight of the ship.

(c) Weight report using the Navy three-digit weight classification system.

For the SES runs, three constraints were imposed on the design: Weight equals buoyancy; cruise and dash speeds are fixed; and, a fixed required operating range. The SES data base is compared of elements from which values of the SES weights, drag, airflow, buoyancy, and weight of fuel can be computed. This data base was set up with length, beam, cushion pressure, and fuel weight as variables whose values are directly changed by the optimization program and from whose values all the other values in the output are ultimately derived.

The weight parametric relationships for the weight of the light ship components are based on as as yet unpublished DTNSRDC report by Fee and Kuklewicz. The constants in these equations have, however, been adjusted so as to agree with several recent 2000 and 3000 point designs.

The buoyancy relations have been adjusted to reflect the actual distribution of buoyancy between the sidewalls and cushion as exists in current SES designs.

The weight of fuel is calculated by making use of the Fee-Kuklewicz drag relations and the required range.

As a simplification, both weight groups 400 and 567 were treated as fixed weight inputs. Weight group 400 is mainly composed of navigation equipment and the command and control portion of the military payload, neither of which would vary over the narrow range that the ship's displacement is changing. Weight group 567, composed of lift engines, fans, and associated ducting, was sized to provide sufficient lift over a variety of sea state conditions. Therefore, weight group 567 was not allowed to vary over the small displacement variations generated. The model was also modified to provide the SES with "rubber" engines that resize to attain the required dash speed.

Stability and trim balances were not made constraints in the optimization program to reduce the cost of the optimization runs. However, checks were made to verify that designs produced did not exceed normal limits.

The following is a summary of the weight functional relationships used for the SES runs:

(1) WT.GRP.100 - f(FL displacement, L/B, cushion length,cushion specific loading)

(2) WT.GRP.200 - f(SHP)

(3) WT.GRP.300 - f(Light Ship Displacement)

(4) WT.GRP.400 - Fixed weight input

(5) WT.GRP.5XX - f(Light Ship Displacement)

(6) WT.GRP.567 - Fixed weight input

(7) WT.GRP.600 - f(Light Ship Displacement

(8) WT.GRP.700 - Fixed weight input

(9) MARGIN - 15% of Sum of WT.GRPS 100 - 700

(10) FUEL - f(crew size, range,speed, FL displacement)

(11) WATER - f(crew size, mission duration)

(12) PROVISIONS - f(crew size, mission duration)

(13) AMMUNITION - Fixed weight input

METHODOLOGY

The methodology used was similiar to that used for generating the marginal weight factors for hydrofoils. That is, develop a set of baseline SES's of varying displacement and then perturb these baselines to obtain the desired marginal factors. However, unlike the case of hydrofoils, significant costs were involved in making the computer ship synthesis runs which resulted in being unable to investigate as many perturbations to the baseline ships as would have been desirable. In particular, it was not financially feasible to investigate the linearity limits of the marginal weight factors for each baseline. In spite of these difficulties, it is felt that sufficient data was generated to accurately determine the marginal weight factors for "reasonable" perturbations from the baseline values and to identify trends between these baselines.

The first step in generating marginal weight factors was to decide on the characteristics of the baseline ships. These baselines would cover the range of displacements from approximately 500 tons through 4000 tons and would vary their operating ranges and speeds as appropriate to each ship size. As a starting point the general characteristics of the ANVCE FAR TERM SES were adopted for a 3500 ton ship and named SES3. Two additional baselines (SES1 and SES2) were then drawn up by modifying the SES3 payload, range, and speed to appropriate values for missions envisioned for the smaller vehicles. The SES2 has an operational range of 1450 nautical miles and is capable of surface warfare (SUW),

anti-submarine warfare (ASW), and anti-air warfare (AAW). It differs from the SES3 in that the SES2 lacks a helicopter capability, has a higher dash speed requirement, operates at the shorter range, carries a military payload of approximately 100 tons, and has a crew size of 79 men. The SES1 is a short range (800 nautical miles) 500 ship with a SUW and ASW capability, a military payload of 95 tons, a dash speed of 90 knots, and a crew of 30 men.

There are two questions of interest that a ship or subsystem designer might ask. First, "given a ship type and a rough estimate of the vessel's size, what will be the full impact of this subsystem on the ship's size and weight"? The perturbations to SES1, SES2, and SES3 are designed to answer this question. A second question might be, "given a specific ship type and size, what would be the full impact of a subsystem on the ship with fixed dimensions"? To answer the second question, a baseline designated SES4 was utilized. SES4 has the identical military and similiar performance characteristics as SES3 but the cushion length and beam were locked at and appropriate value. A summary of the performance characteristics for the SES baselines may be found in Table 4.1.

Once having settled upon the general characteristics of the baselines, the next step was to use the SES computer model to produce an optimized design for the baseline ships. This was done for SES1, SES2, and SES3 by holding the range, speed, payload, and crew size constant while allowing the model to resize the ship as necessary to

Table 4.1

PERFORMANCE CHARACTERISTICS OF THE SES BASELINES

		SES1	SES2	SES3	SES4
capability	SUW	●	●	●	●
	ASW	●	●	●	●
	AAW		●	●	●
	HELO			●	●
characteristic	RANGE (NM)	800	1450	3000	3000
	DASH SPEED (KTS)	90	85	80	80
	CRUISE SPEED (KTS)	50	55	60	68
	CREW SIZE	30	79	141	141
	MILITARY P/L (TONS)	95	100	290	290

find a minimum weight ship subject to the performance constraints that were detailed above. For SES4, the additional constraint of not allowing the ship's dimensions to vary was added. A summary of the principal physical characteristics for each of the four baselines may be found in Table 4.2.

Having produced four optimized baseline designs, the next step was to vary the individual payload support parameters and note the resulting change in the baseline ship. The parameters that were varied are:

(1) Payload Weight - Both positive and negative perturbations of the baseline values were investigated. The payload weight was changed by varying WT.GRP.700 ± 50% from the baseline value.

(2) Crew Size - The size of the crew is an input to the model and was varied directly. With the SES ship synthesis model, no volume balance is performaed, hence there is no difference between the addition of one officer or one enlisted man.

(3) Electrical Load - The model does not have electrical load as a direct input. Therefore, it was decided to use the HANDE hydrofoil computer model KW/WT.GRP.300 estimating relationship of WT.GRP.300 = 0.02 X KW. This relationship was derived for gas turbine powered generators which is a reasonable assumtion for use on an SES. To perform the

Table 4.2

SES BASELINE SHIPS PHYSICAL CHARACTERISTICS

PHYSICAL CHARACTERISTIC	SES1	SES2	SES3	SES4
L/B	3.35	3.17	2.59	2.87
LOA (FT)	150.6	207.9	281.1	303.3
BEAM (FT)	53.5	67.0	106.2	105.0
CUSH. LENGTH (FT)	128.7	165.1	235.8	257.9
CUSH. BEAM (FT)	38.5	52.0	91.2	90.0
FULL LOAD (TONS)	645.4	1231.3	3864.9	4271.7
WT.GRP.100 (TONS)	134.7	279.4	1002.4	1202.1
WT.GRP.200 (TONS)	118.6	195.7	350.0	354.8
WT.GRP.300 (TONS)	8.1	21.0	74.9	84.4
WT.GRP.400 (TONS)	5.4	20.6	74.0	74.0
WT.GRP.5XX (TONS)	30.3	55.7	125.4	141.3
WT.GRP.567 (TONS)	45.8	63.7	127.4	127.4
WT.GRP.600 (TONS)	35.7	50.6	218.4	245.9
WT.GRP.700 (TONS)	20.0	45.2	63.0	63.0
MARGIN (TONS)	59.8	110.0	305.8	344.1
LIGHT SHIP (TONS)	457.8	842.3	2341.0	2636.9
FUEL (TONS)	98.9	304.0	1285.2	1396.1
KW LOAD (KW)	405	1052	3745	4220
HULL VOL. (FT^3)	110,623	276,519	602,262	652,020
CUSHION AREA (FT^2)	4948	8589	21,504	23,215
CUSH. PRESS (LB/FT^2)	287.6	309.7	366.8	376.2
PROPULSION SHP	151,142	171,670	239,900	243,192

necessary perturbations, the desired KW variation was converted to a WT.GRP.300 weight and then inputted to the model.

(4) Space - Inasmuch as the model does not perform a volume balance between the required and available volumes, it was necessary to increase the cushion size and then fix the ship size at the new dimensions. Although fixing the ship's size does not allow for the full impact of space to be demonstrated, it is felt that the error involved is extremely small for the SES which is a weight sensitive ship.

The final step is to plot the weight changes that result from the perturbations described above versus the change in the support parameter. The slopes of the resulting plots are, by definition, the desired marginal weight factors.

RESULTS

The results of the perturbations for the SES2 baseline are presented in Tables 4.3, 4.4, 4.5, and 4.6 while the results for the other baselines may be found in Appendix III. The columns labeled "NEW" contain the output of the ship synthesis model as a result of the specific variations. The "DIFF" column contains the change from the baseline values.

For the cases of payload weight, crew size, and electrical load variations, the weight groups and the full load displacement reacted as would be expected. It is worth noting, however, that the L/B ratio tended to shrink as weight, men, and electrical capacity were added to the baselines. The reason for this trend is that the model increases the cushion area to support the added weight rather than substantially increasing the cushion pressure which would in turn increase the drag. The decrease in L/B indicates that the model attaches a greater structural weight penalty to a growth in length rather than width.

Table 4.6 illustrates the space variation for SES2 with the ship's principal dimensions locked at values that give and additional 500 square feet of cushion area over that of the baseline SES2. The results are quite interesting. Structural weight (WT.GRP.100) has, as would be expected, increased; however, the propulsion plant weight (WT.GRP.200) and the fuel weight have both decreased. These changes are reasonable since the cushion pressure has decreased thereby lowering the total hydrodynamic drag.

Table 4.3

SES2 PAYLOAD WEIGHT VARIATION

VARIATION	BASELINE	-10 TONS		+10 TONS		+20 TONS		
ITEM	VALUES	NEW	DIFF	NEW	DIFF	NEW	DIFF	
LBP	207.9	206.9	- 0.9	208.8	+ 0.9	209.7	+ 1.8	(1)
L/B	3.17	3.20	+0.03	3.15	-0.02	3.12	-0.05	
F.L. DISP	1231.3	1192.9	-38.4	1269.6	+38.3	1307.8	+76.5	(2)
WT.GRP.100	279.7	271.5	- 8.2	288.0	+ 8.3	296.3	+16.6	
WT.GRP.200	195.7	191.6	- 4.1	199.8	+ 4.1	203.7	+ 8.0	
WT.GRP.300	21.0	20.3	- 0.7	21.8	+ 0.8	22.6	+ 1.6	
WT.GRP.400	20.6	20.6	- - -	20.6	- - -	20.6	- - -	
WT.GRP.5XX	55.7	53.7	- 2.0	57.8	+ 2.1	59.8	+ 4.1	(3)
WT.GRP.567	63.7	63.7	- - -	63.7	- - -	63.7	- - -	
WT.GRP.600	50.6	48.7	- 1.9	52.4	+ 1.8	54.3	+ 3.7	
WT.GRP.700	45.2	35.2	-10.0	55.2	+10.0	65.2	+20.0	
LIGHT SHIP	842.3	811.2	-31.1	873.3	+31.0	904.4	+62.1	(4)
FUEL	304.0	296.7	- 7.3	311.3	+ 7.3	318.5	+14.5	
CUSH PRESS	309.7	305.6	- 4.1	313.6	+ 3.9	317.4	+ 7.7	(5)

NOTES:

(1) Length in feet.

(2) All weights in units of Long Tons.

(3) WT.GRP.5XX includes all of WT.GRP.500 less WT.GRP.567.

(4) Light Ship weight includes a 15% Margin.

(5) Cushion Pressure in units of LBS/FT^2

Table 4.4

SES2 CREW SIZE VARIATION

VARIATION	BASELINE	-10 MEN		+10 MEN		
ITEM	VALUES	NEW	DIFF	NEW	DIFF	
LBP	207.9	207.6	- 0.3	208.2	+ 0.3	(1)
F.L. DISP.	1231.3	1219.8	-11.5	1242.8	+11.5	(2)
WT.GRP.100	279.7	277.3	- 2.4	282.2	+ 2.5	
WT.GRP.200	195.7	194.5	- 1.2	196.9	+ 1.2	
WT.GRP.300	21.0	20.9	- 0.1	21.2	+ 0.2	
WT.GRP.400	20.6	20.6	- - -	20.6	- - -	
WT.GRP.5XX	55.7	55.4	- 0.3	56.1	+ 0.4	(3)
WT.GRP.567	63.7	63.7	- - -	63.7	- - -	
WT.GRP.600	50.6	50.3	- 0.3	50.9	+ 0.3	
WT.GRP.700	45.2	45.2	- - -	45.2	- - -	
LIGHT SHIP	842.3	837.2	- 5.1	847.4	+ 5.1	(4)
FUEL	304.0	301.8	- 2.2	306.2	+ 2.2	
CUSH PRESS	309.7	308.4	- 1.3	310.8	+ 1.1	(5)
L/B	3.17	3.18	+0.01	3.16	-0.01	
LOADS	84.1	79.8	- 4.3	88.1	+ 4.0	

NOTES:

(1) Length in feet.
(2) All weights in Long Tons.
(3) WT.GRP.5XX includes all of WT.GRP500 less 567.
(4) Light Ship weight includes a 15% Margin.
(5) Cushion Pressure in units of LBS/FT^2.

Table 4.5

SES2 ELECTRICAL LOAD VARIATION

VARIATION	BASELINE	+ 125 KW		+ 250 KW		
ITEM	VALUES	NEW	DIFF.	NEW	DIFF.	
LBP	207.9	208.0	+ 0.1	208.1	+ 0.2	(1)
L/B	3.17	3.16	- .01	3.15	- .02	
F.L.DISP.	1231.3	1241.0	+ 9.7	1250.8	+19.5	(2)
WT.GRP.100	279.7	281.6	+ 1.9	283.5	+ 3.8	
WT.GRP.200	195.7	196.9	+ 1.2	198.0	+ 2.3	
WT.GRP.300	21.0	23.8	+ 2.8	26.5	+ 5.5	
WT.GRP.400	20.6	20.6	- - -	20.6	- - -	
WT.GRP.5XX	55.7	56.2	+ 0.5	56.8	+ 1.1	(3)
WT.GRP.567	63.7	63.7	- - -	63.7	- - -	
WT.GRP.600	50.6	51.0	+ 0.4	51.5	+ 0.9	
WT.GRP.700	45.2	45.2	- - -	45.2	- - -	
LIGHT SHIP	842.3	850.0	+ 7.7	857.8	+15.5	(4)
FUEL	304.0	306.0	+ 2.0	308.0	+ 4.0	
KW LOAD	1052	1188	+ 136	1326	+ 274	(5)
CUSH PRESS	309.7	311.0	+ 1.3	312.3	+ 2.6	(6)

NOTES:

(1) Length in feet
(2) All weights in Long Tons.
(3) WT.GRP.5XX includes all of WT.GRP.500 less WT.GRP.567.
(4) Light Ship weight includes a 15% Margin
(5) KW load in Kilowatts
(6) Cushion Pressure in units of LBS/FT^2

Table 4.6

SES2 SPACE VARIATION

VARIATION	BASELINE	+ 500 FT^2	
ITEM	VALUES	NEW	DIFF.
LBP	207.9	212.6	+ 4.7	(1)
L/B	3.17	3.17	- - -
F.L. DISP.	1231.3	1234.5	+ 3.2	(2)
WT.GRP.100	279.7	295.3	+15.6
WT.GRP.200	195.7	188.8	- 6.9
WT.GRP.300	21.0	21.3	+ 0.3
WT.GRP.400	20.6	20.6	- - -
WT.GRP.5XX	55.7	56.5	+ 0.8	(3)
WT.GRP.567	63.7	63.7	- - -
WT.GRP.600	50.6	51.3	+ 0.7
WT.GRP.700	45.2	45.2	- - -
LIGHT SHIP	842.3	854.2	+11.9	(4)
FUEL	304.0	295.3	- 8.7
CUSH. AREA	8589	9089	+ 500	(5)
CUSH. PRESS	309.7	293.4	-16.3	(6)

NOTES:

(1) Length in feet.
(2) All weights in Long Tons.
(3) WT.GRP.5XX includes all of WT.GRP.500 less WT.GRP.567.
(4) Light Ship weight includes a 15% Margin.
(5) Cushion Area in units of FT^2.
(6) Cushion Pressure in units of LBS/FT^2.

To remove space from an SES gives results quite different from that found for hydrofoils or displacement ships. Instead of the full load displacement decreasing as the ship shrinks, the total weight of the ship in fact increases. Structural weight does decrease but the increased drag due to a higher cushion pressure cause the propulsion plant and fuel weights to increase. Table 4.7 illustrates the differences between a positive and negative space perturbations on SES3.

The space variations that were investigated presuppose that the size of the cushion area is being modified to effect the required change in space. If, on the other hand, a small compartment was added to the superstructure without changing the cushion dimensions, then the impact of this space would be approximately the weight of the compartment's structure multiplied by the marginal weight factor for payload weight.

Figures 4.1, 4.2, 4.3, and 4.4 were generated by plotting the data in Tables 4.3, 4.4, 4.5, and 4.6. The change in the support parameter is plotted versus the corresponding change in full load displacement. These figures are of value in that they illustrate the relative size of the variation in the different weight groups; the degree of linearity of the results; and, the slope of the plots are the marginal weight factors for SES2.

Tables 4.8, 4.9, 4.10, and 4.11 contain the marginal weight factors of the four SES baselines for the variation in the payload support parameters of payload weight, crew size, electrical power, and space. The marginal weight factors for full load displacement are plotted versus

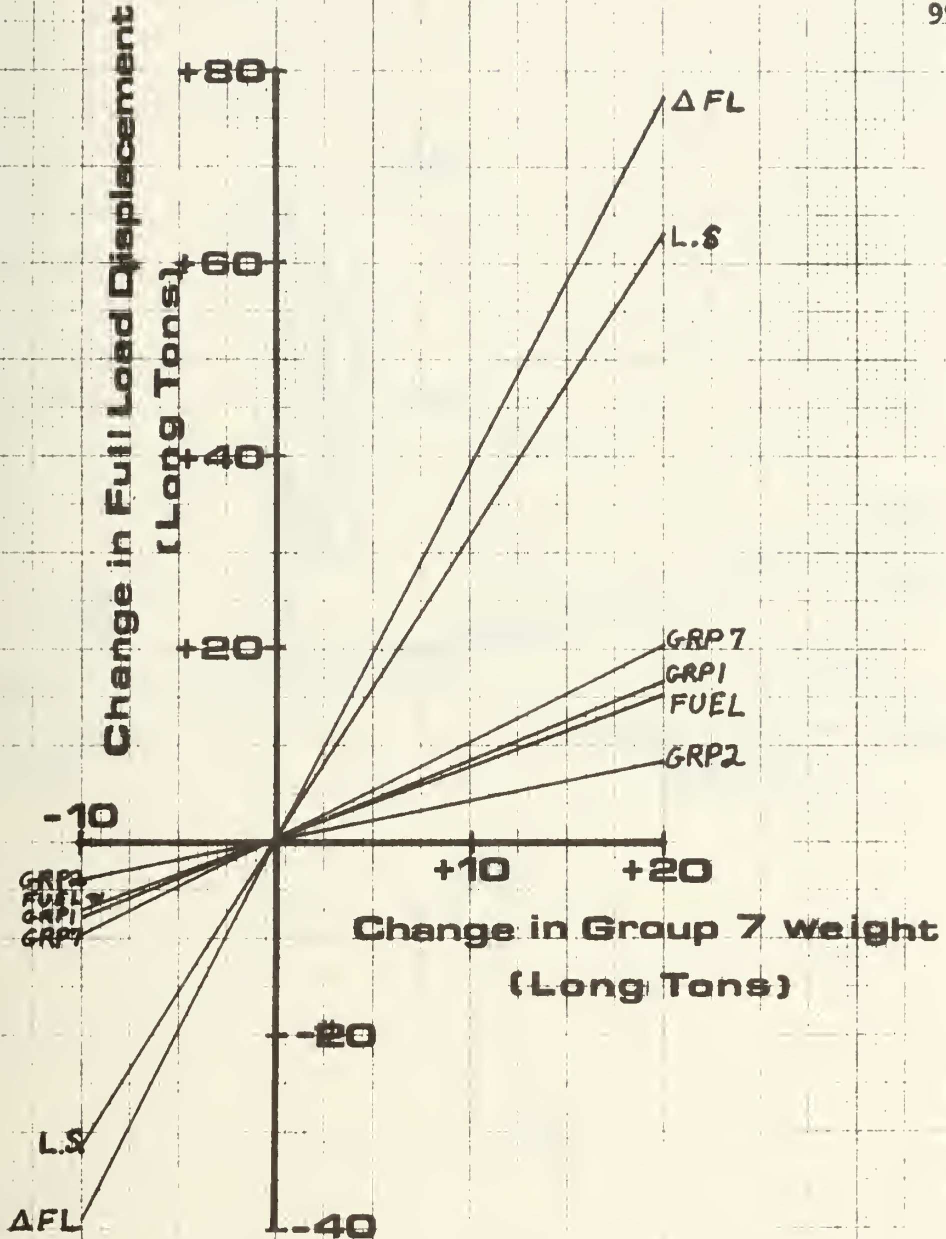
Table 4.7

SES3 SPACE VARIATION

VARIATION	BASELINE	- 1009 FT^2		+ 990 FT^2		
ITEM	VALUES	NEW	DIFF.	NEW	DIFF.	
LBP	281.1	275.4	- 5.7	286.4	+ 5.3	(1)
L/B	2.59	2.59	- - -	2.59	- - -	
F. L. DISP.	3864.9	3876.3	+11.4	3873.7	+ 8.8	(2)
WT.GRP.100	1002.4	966.7	-35.7	1039.9	+37.5	
WT.GRP.200	350.0	364.8	+14.8	339.2	-10.8	
WT.GRP.300	74.9	73.9	- 1.0	76.1	+ 1.2	
WT.GRP.400	74.0	74.0	- - -	74.0	- - -	
WT.GRP.5XX	125.4	123.8	- 1.6	127.5	+ 2.1	(3)
WT.GRP.567	127.4	127.4	- - -	127.4	- - -	
WT.GRP.600	218.4	215.5	- 2.9	221.9	+ 3.5	
WT.GRP.700	63.0	63.0	- - -	63.0	- - -	
LIGHT SHIP	2341.0	2310.8	-30.2	2379.6	+38.6	(4)
FUEL	1285.2	1326.8	+41.6	1255.4	-29.8	
CUSH. AREA	21504	20495	-1009	22494	+ 990	(5)
CUSH. PRESS	366.8	386.9	+20.1	350.8	-16.0	(6)

NOTES:

(1) Length in feet.
(2) All weights in Long Tons.
(3) WT.GRP.5XX includes all of WT.GRP.500 less WT.GRP.567.
(4) Light Ship weight includes a 15% Margin.
(5) Cushion Area in units of FT^2.
(6) Cushion Pressure in LBS/FT^2.



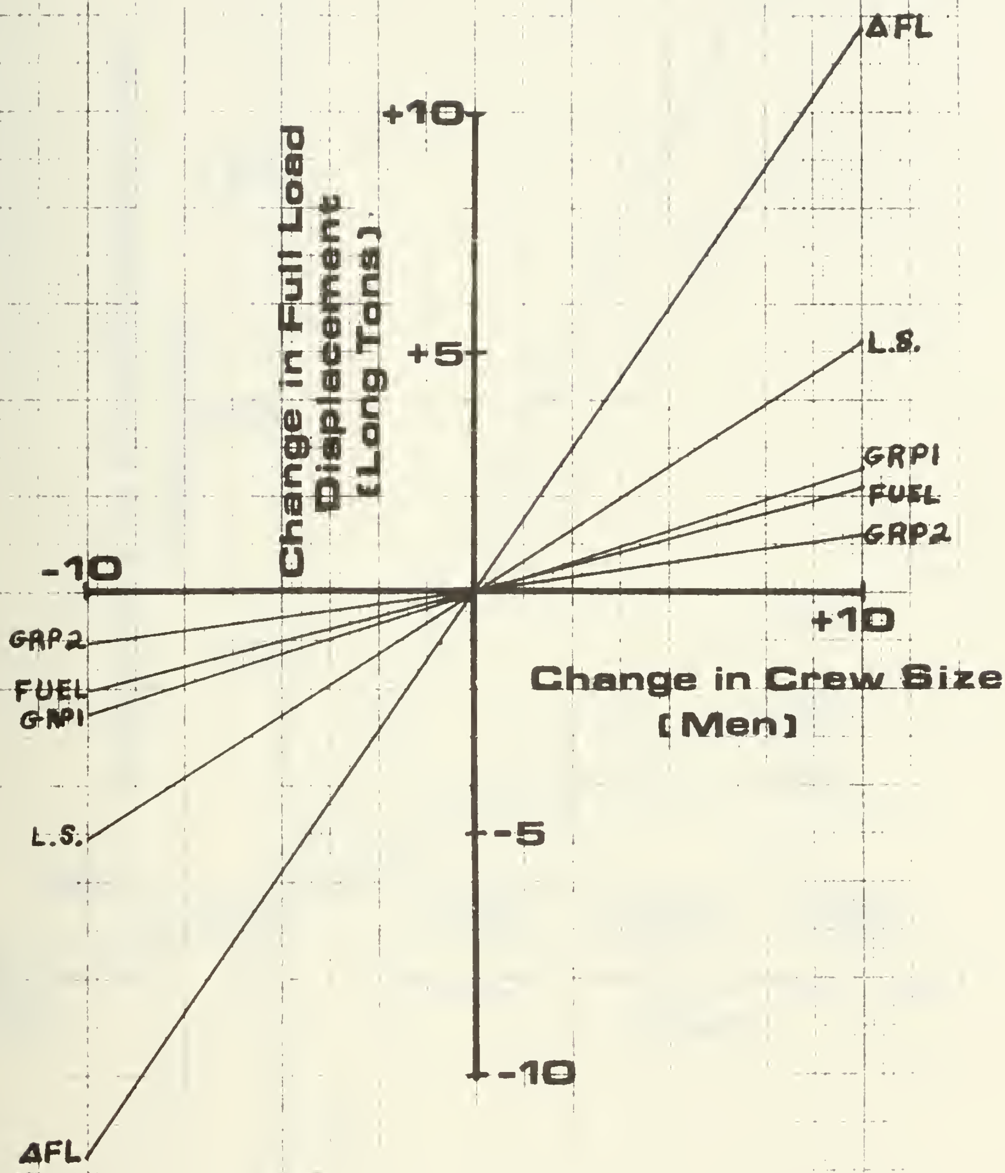
SES2

Change in Full Load Displacement

VS

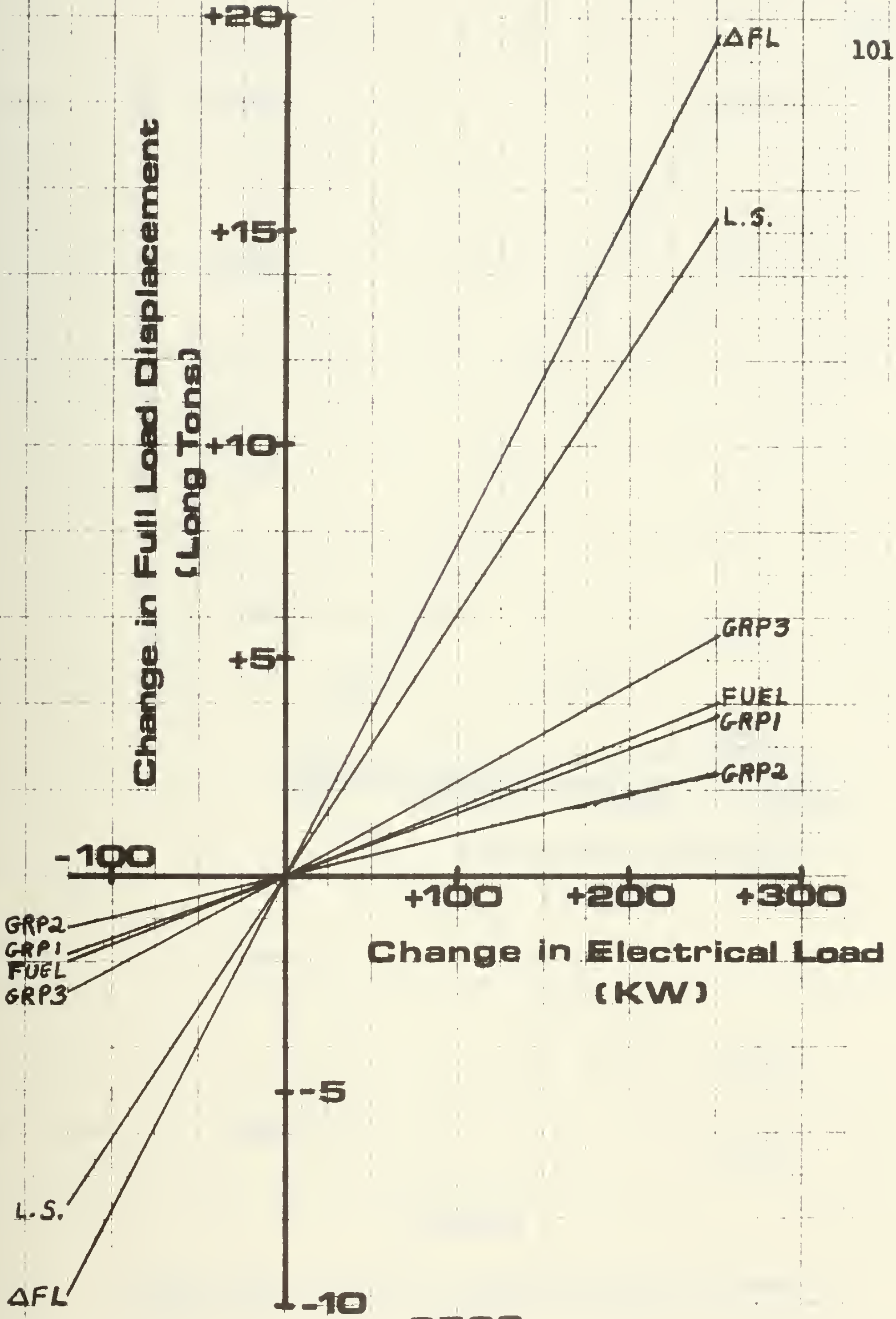
Change in Payload Weight

Figure 4.1



Change in Full Load Displacement
VS
Change in Crew Size

Figure 4.2



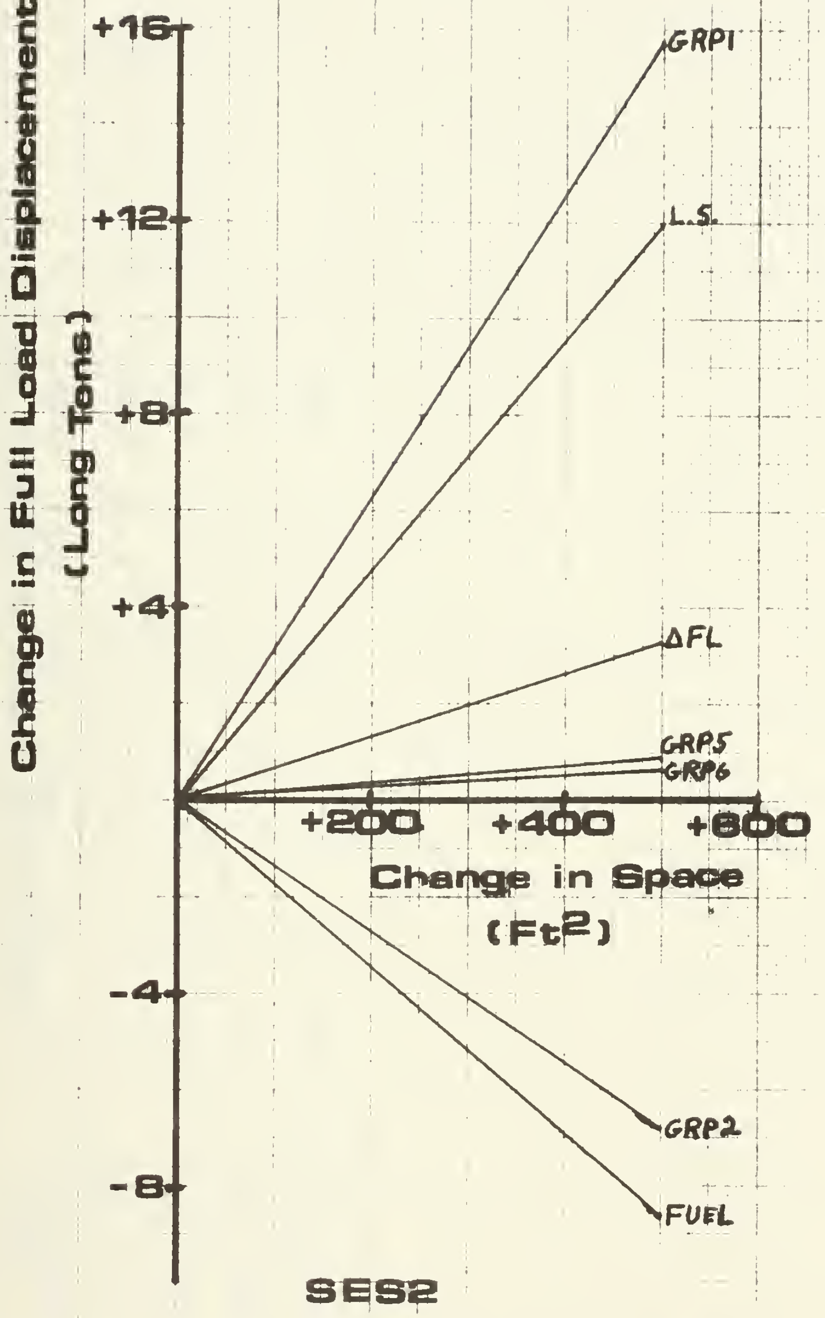
SES2

Change in Full Load Displacement

VS

Change in Electrical Load

Figure 4.3



Change in Full Load Displacement

VS

Change in Space

Figure 4.4

Table 4.8

SES MARGINAL WEIGHT FACTORS FOR PAYLOAD WEIGHT VARIATION

SHIP NO	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/TONS)					
		Δ FL	L.S.	GRP1	GRP2	GRP7	FUEL
1	650T - SES	3.18	2.81	0.53	0.38	1.00	0.38
2	1250T - SES	3.83	3.10	0.83	0.40	1.00	0.72
3	3800T - SES	5.56	3.97	1.33	0.41	1.00	1.59
4	4K FIXED SES	6.24	3.63	0.77	0.75	1.00	2.68

Table 4.9

SES MARGINAL WEIGHT FACTORS FOR CREW SIZE VARIATION

SHIP NO	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/MAN)					
		Δ FL	L.S.	GRP1	GRP2	LOADS	FUEL
1	650T - SES	0.93	0.42	0.10	0.12	0.41	0.12
2	1250T - SES	1.15	0.51	0.25	0.12	0.41	0.22
3	3800T - SES	1.60	0.72	0.38	0.12	0.41	0.46
4	4K FIXED SES	1.79	0.62	0.22	0.21	0.42	0.75

Table 4.10

SES MARGINAL WEIGHT FACTORS FOR ELECTRICAL LOAD VARIATION

SHIP NO	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/KW)					
		Δ FL	L.S.	GRP1	GRP2	GRP3	FUEL
1	650T - SES	0.068	0.060	0.007	0.009	0.022	0.009
2	1250T - SES	0.078	0.062	0.015	0.010	0.022	0.016
3	3800T - SES	0.110	0.080	0.020	0.010	0.022	0.035
4	4K FIXED SES	0.125	0.073	0.015	0.016	0.022	0.052

Table 4.11

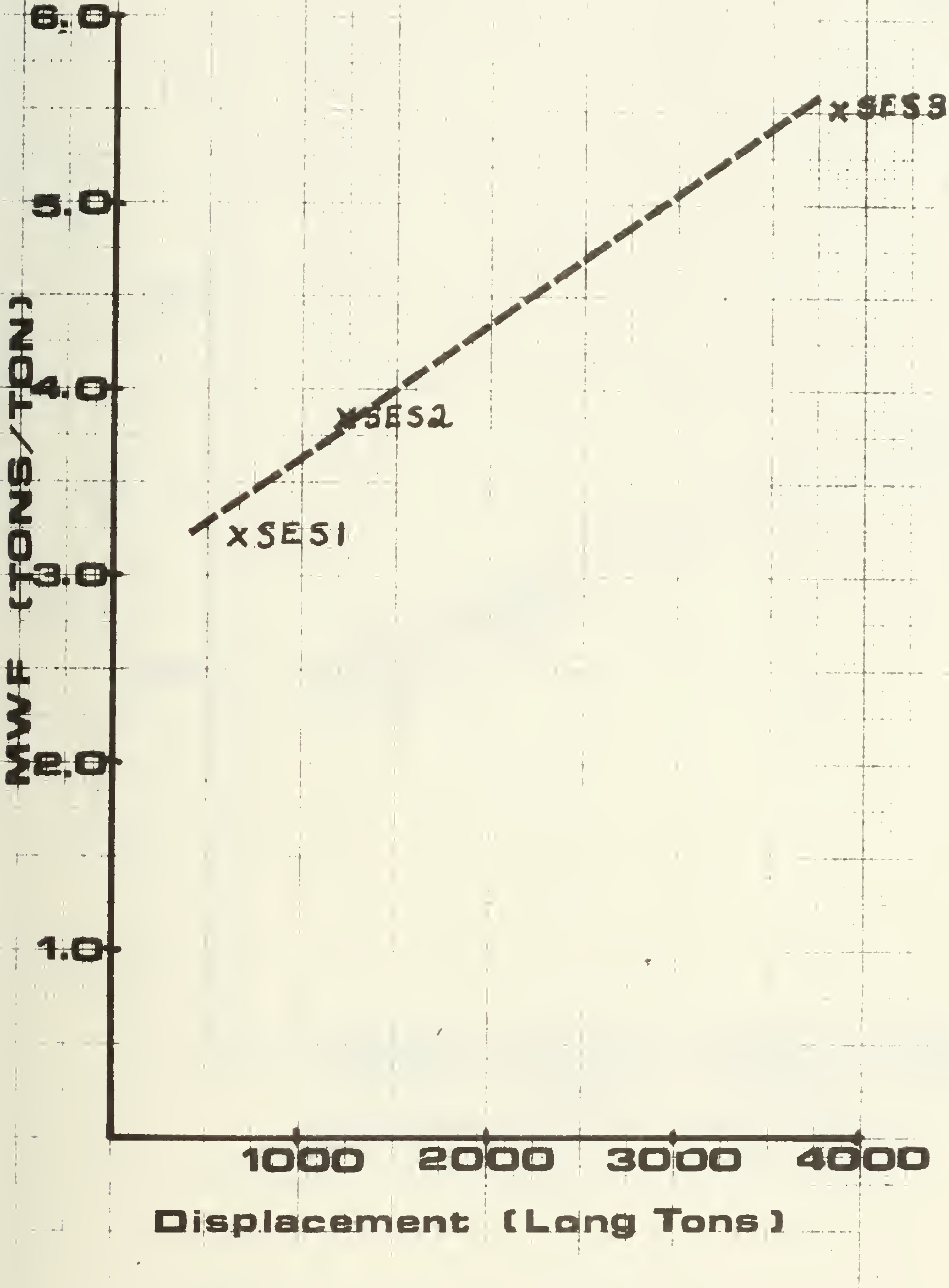
SES MARGINAL WEIGHT FACTORS FOR POSITIVE SPACE VARIATION

SHIP NO	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS ($TONS/FT^2$)				
		Δ FL	L.S.	GRP1	GRP2	FUEL
1	650T - SES	0.0047	0.0160	0.0240	-0.0141	-0.0110
2	1250T - SES	0.0064	0.0238	0.0312	-0.0138	-0.0174
3	3800T - SES	0.0089	0.0390	0.0379	-0.0110	-0.0301

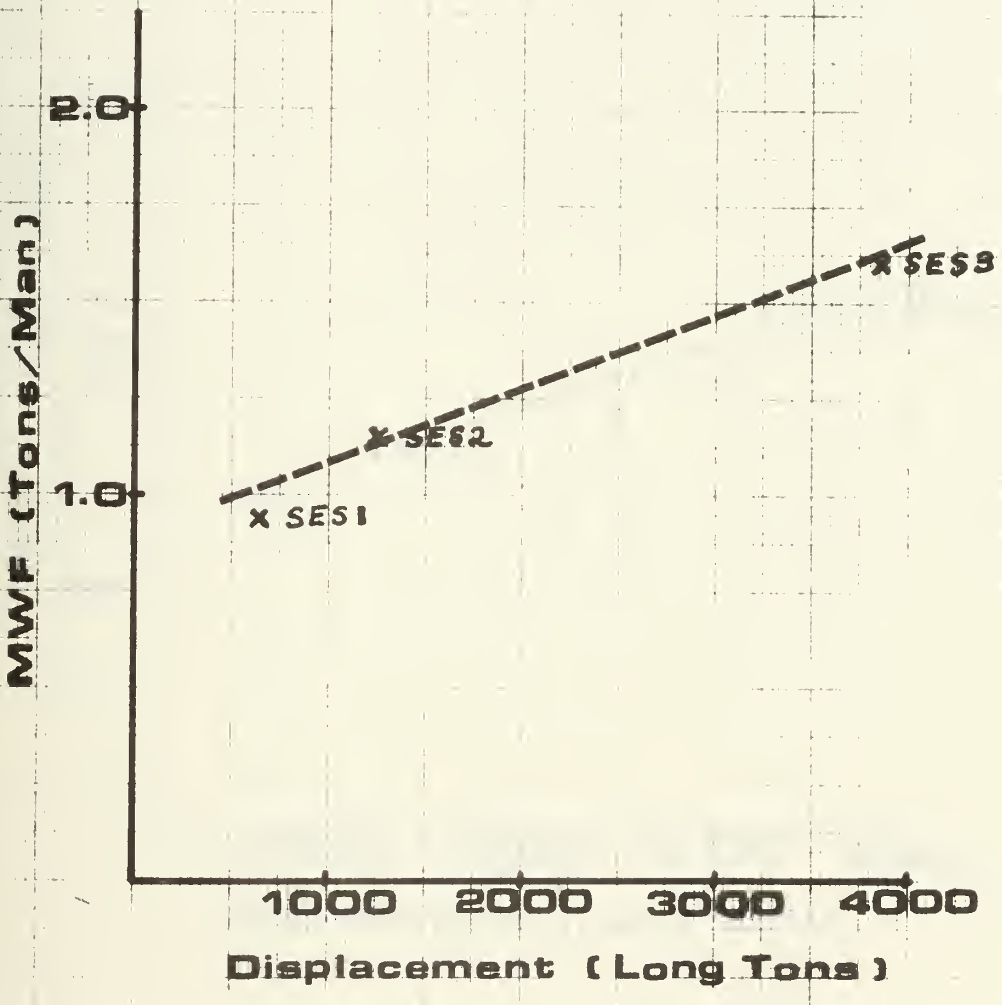
the corresponding SES's full load displacement in Figures 4.5, 4.6, 4.7, and 4.8. These figures indicate that the marginal weight factors for SES's do increase in size as the full load displacement increases. The reason for this increase is the strong impact that the range of the vessel has on the size of marginal weight factors since range appears as a multiplication factor in the fuel and provision estimating relationships.

Perturbations of payload weight, crew size, and electrical load were investigated for SES4. The results, shown in Tables 4.8, 4.9, and 4.10, show that the ship, unable to resize, is forced to add fuel and propulsion plant weight to meet the performance requirements. An unconstrained SES optimizes by balancing the design for minimum structural, propulsion, and fuel weights. The larger marginal weight factors for SES4 indicate that the design is not optimized with regard to cushion size.

As was done with hydrofoils, a synthesis run was made varying several parameters simultaneously to demonstrate the additive property of marginal weight factors. For this run, using the SES3 baseline, the payload weight was increased by 45 tons, the crew size was increased by 8 men, and 350 KW were added to the baseline's electrical load. The results are compard with the sum of the individual effects predicted by marginal weight factors. Table 4.12 presents the comparison while illustrating that the individual effects are additive and marginal weight factors can be used to predict the total impact of a subsystem. The error between actual and predicted impact is less than 2%.

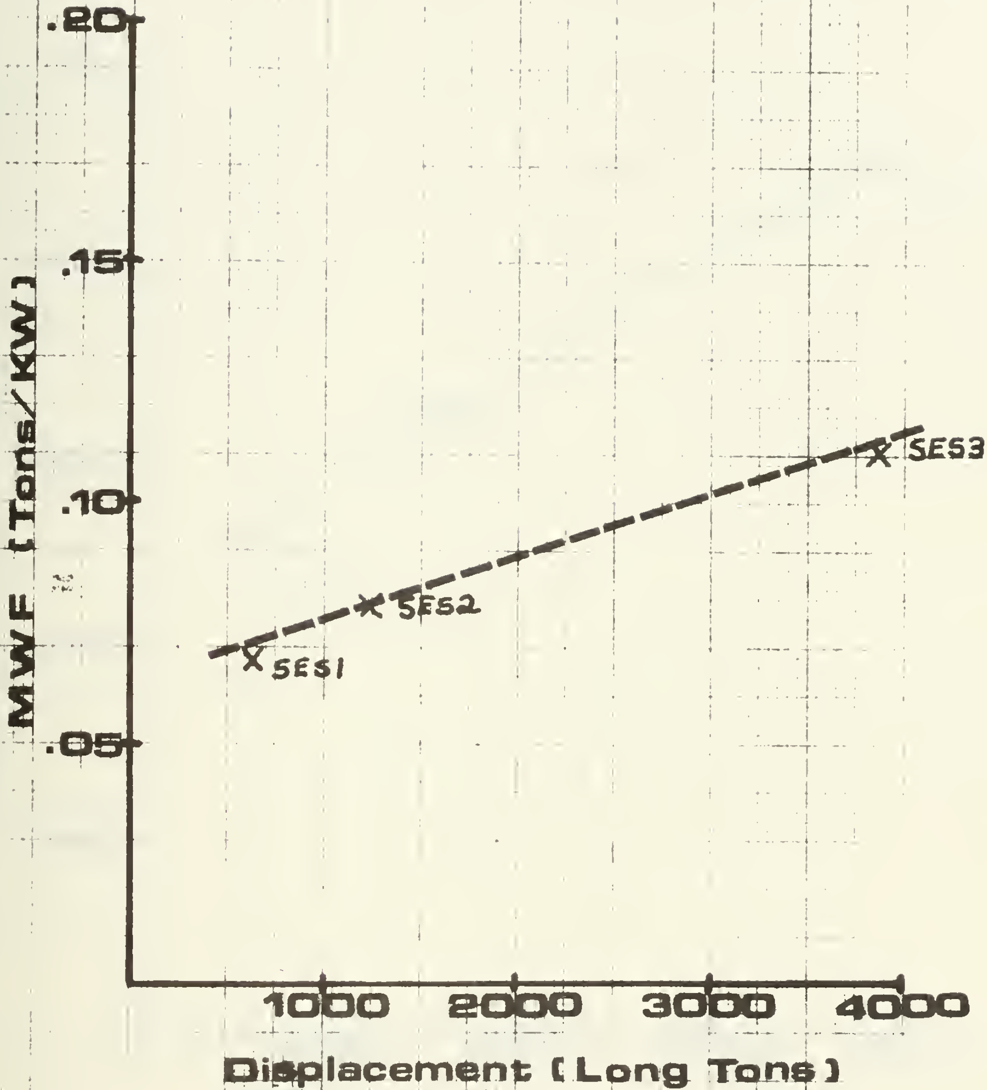


MWF For Payload Weight
VS
Full Load Displacement
Figure 4.5



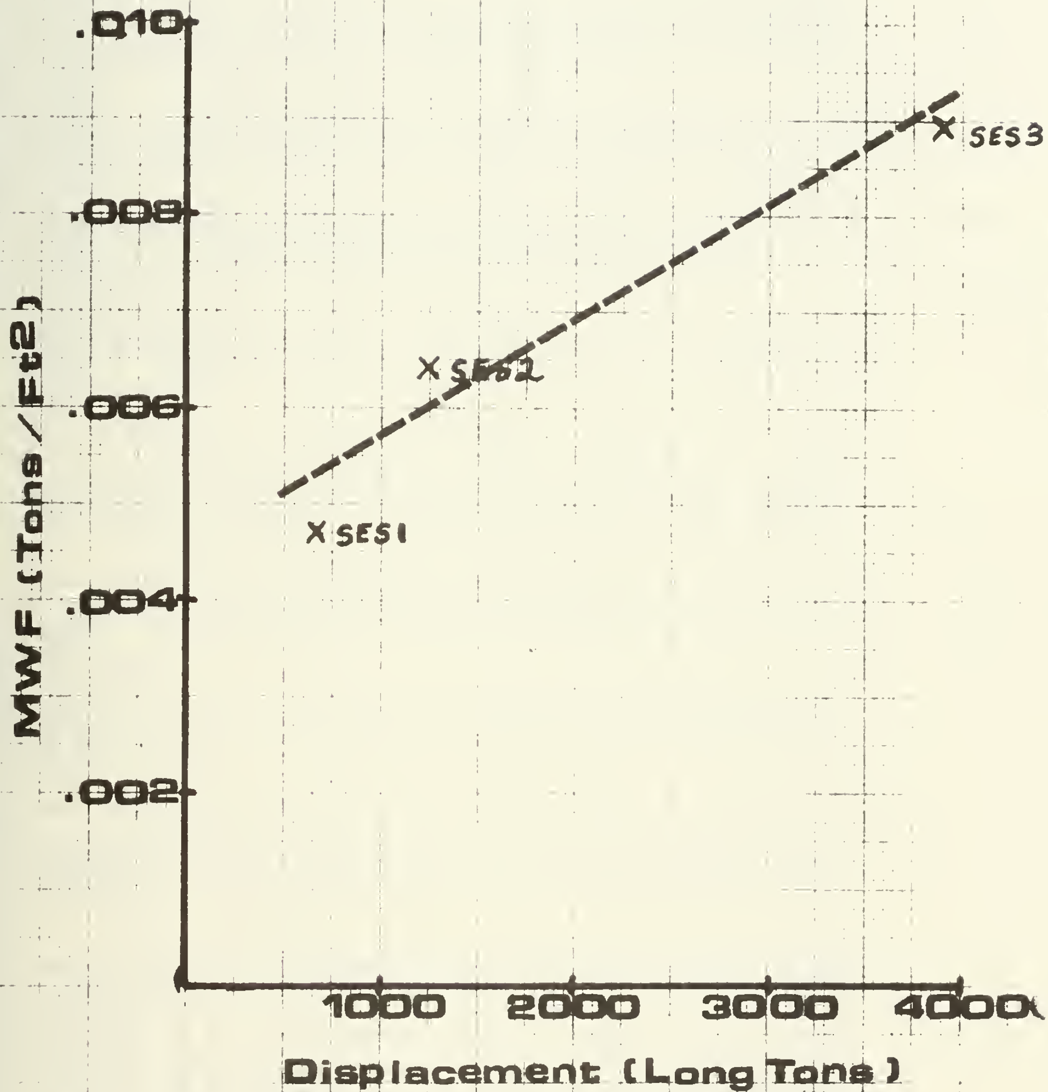
MWF For Crew Size
VS
Full Load Displacement

Figure 4.6



MWF For Electrical Load
VS
Full Load Displacement

Figure 4.7



MWF For Space
VS
Full Load Displacement

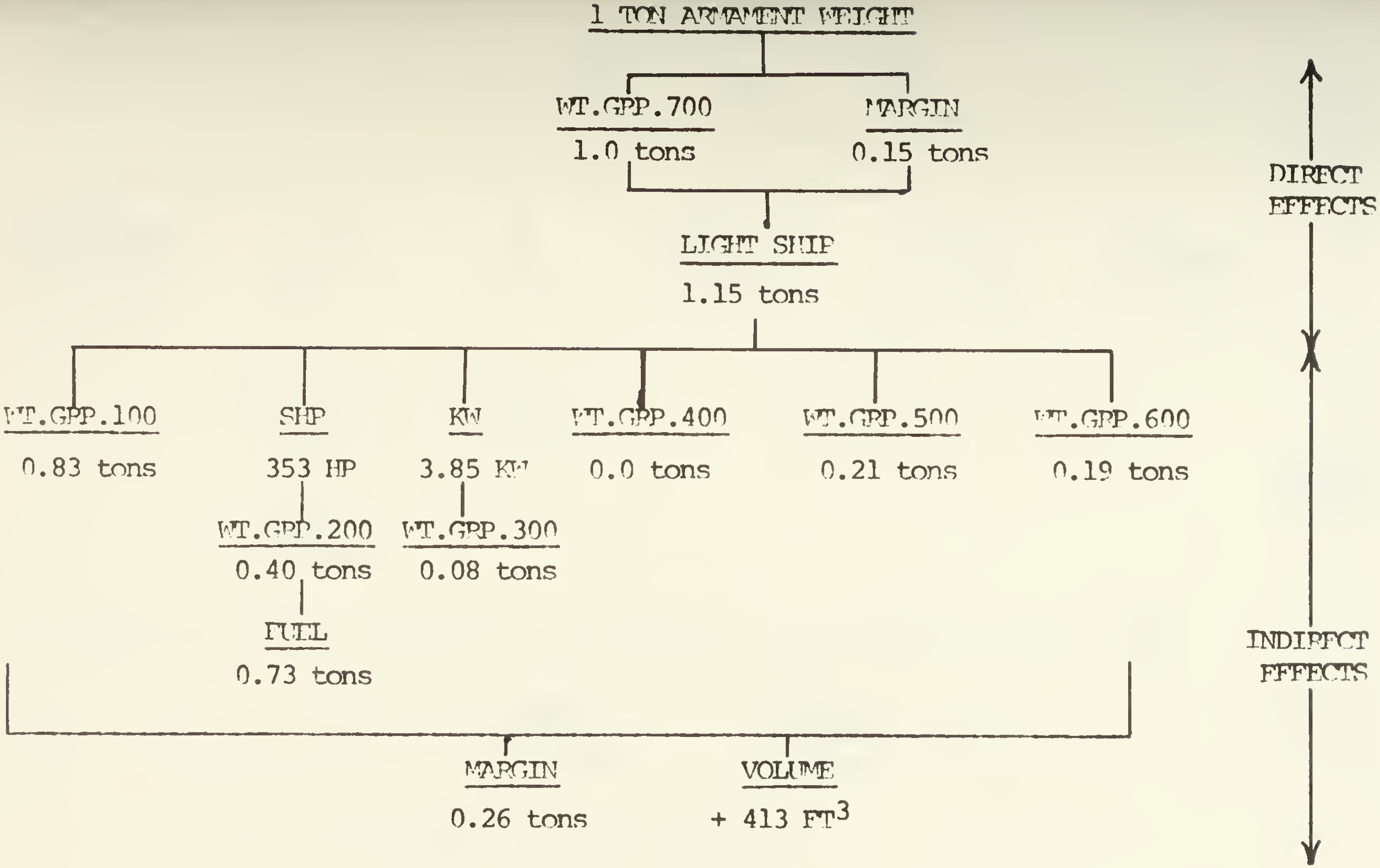
Figure 4.8

Table 4.12

COMPARISON OF ACTUAL IMPACT OF +45 TONS WEIGHT, 8 MEN, AND 350 KW ADDED TO SES3 WITH THE IMPACT PREDICTED BY THE MARGINAL WEIGHT FACTORS.

	MWF FOR WEIGHT	PREDICTED IMPACT FOR + 45 TONS	MWF FOR CREW	PREDICTED IMPACT FOR + 8 MEN	MWF FOR ELEC.	PREDICTED IMPACT FOR + 350 KW	TOTAL PREDICTED IMPACT	ACTUAL IMPACT (ARCJ6)
FULL LOAD	5.56	250.2	1.60	12.8	0.11	38.5	301.5	307.3
WT.GRP.100	1.33	59.8	0.38	3.0	0.02	7.0	69.8	72.8
WT.GRP.200	0.41	18.5	0.12	1.0	0.01	3.5	23.0	23.0
WT.GRP.300	0.13	5.9	0.02	0.2	0.02	7.0	13.1	14.5
WT.GRP.400	0.00	0.0	0.00	0.0	0.00	0.0	0.0	0.0
WT.GRP.5XX	0.21	9.5	0.04	0.3	0.004	1.4	11.2	11.5
WT.GRP.567	0.00	0.0	0.00	0.0	0.00	0.0	0.0	0.0
WT.GRP.600	0.37	16.7	0.07	0.6	0.007	2.5	19.8	19.9
WT.GRP.700	1.00	45.0	0.00	0.0	0.00	0.0	45.0	45.0
LIGHT SHIP	3.97	178.7	0.72	5.8	0.08	28.0	212.5	214.8
FUEL	1.59	71.6	0.46	3.7	0.035	12.3	87.6	89.1

Figures 4.9, 4.10, 4.11, and 4.12 show a breakdown of the marginal weight factors of weight, manning, electrical load, and space respectively. These breakdowns illustrate the differences between the hydrofoil and the SES models. For example, Figure 4.9 shows that the payload weight does not cause a direct effect on weight group 300 as it does in the HANDF model (see Figure 3.11).

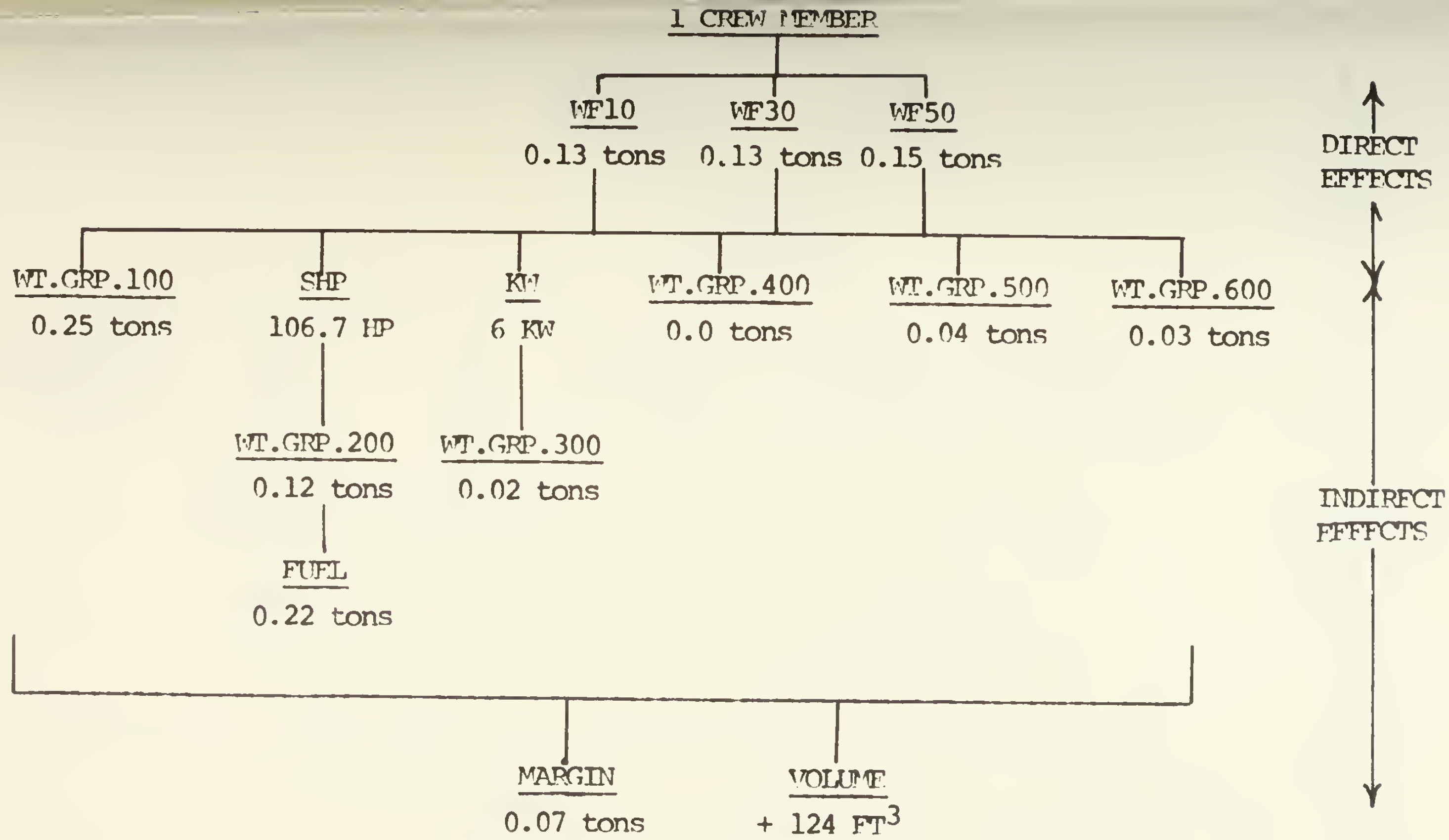


DIRECT WEIGHTS = 1.15 tons

INDIRECT WEIGHTS = 2.68 tons

TOTAL WEIGHT IMPACT = 3.83 tons TOTAL VOLUME IMPACT = 413 FT^3

Figure 4.9 - Breakdown of MWF for addition of 1 ton of Payload weight to WT.GRP.700 on SES2

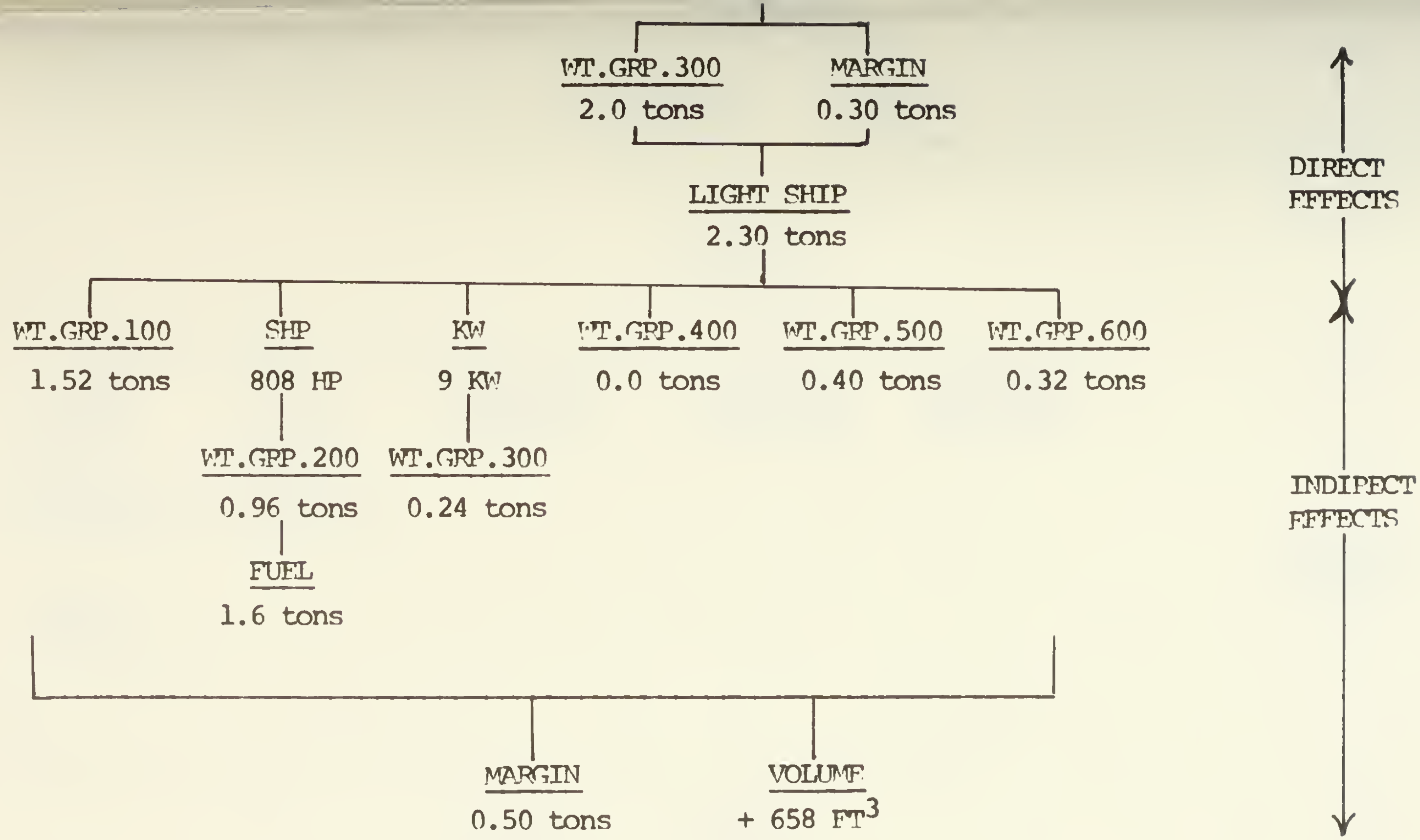


DIRECT WEIGHTS = 0.41 tons

INDIRECT WEIGHTS = 0.74 tons

TOTAL WEIGHT IMPACT = 1.15 tons   TOTAL VOLUME IMPACT = 124 FT^3

Figure 4.10 - Breakdown of MWF for addition of 1 man to SES2

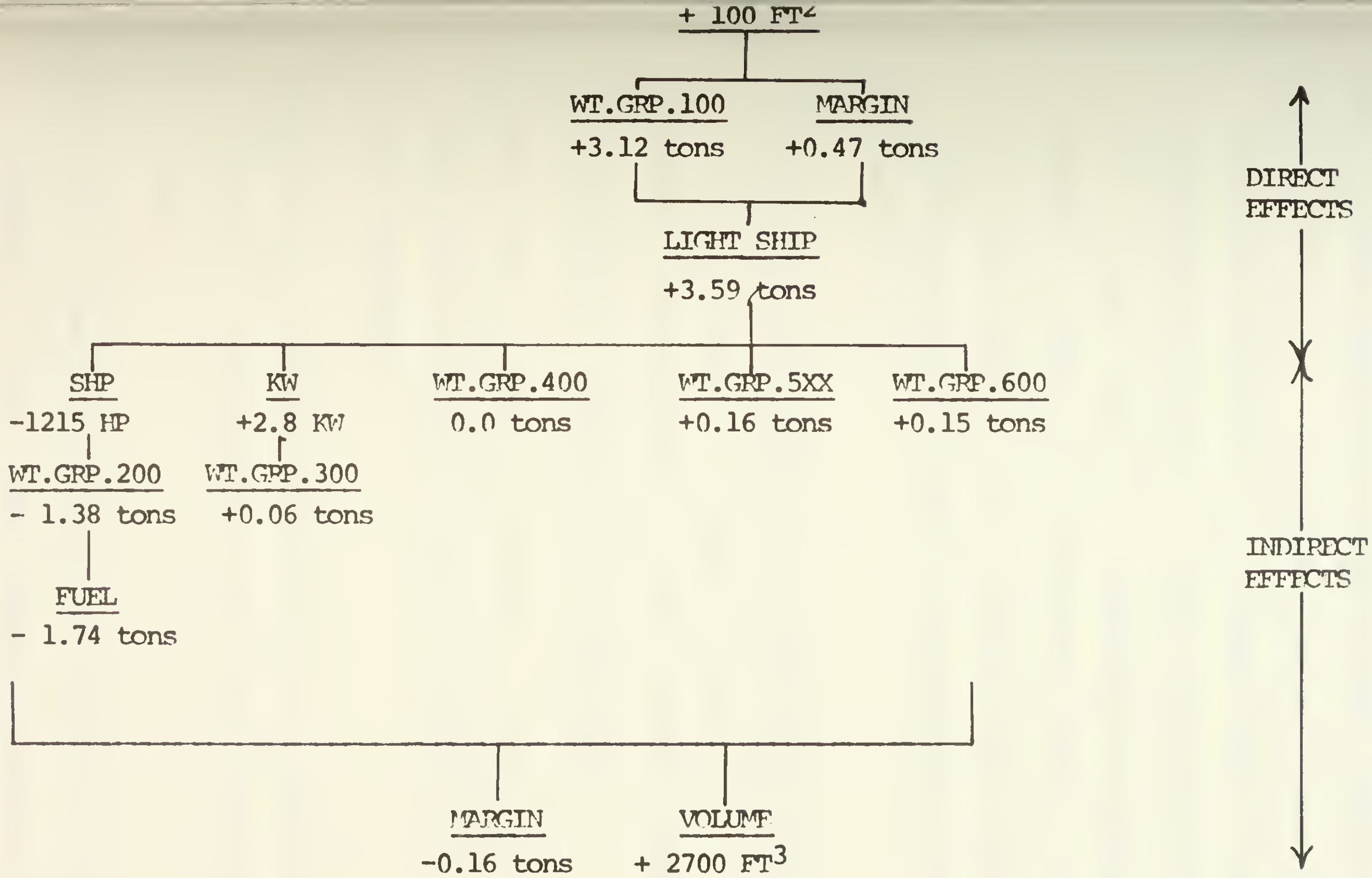


DIRECT WEIGHTS = 2.30 tons

INDIRECT WEIGHTS = 5.50 tons

TOTAL WEIGHT IMPACT = 7.80 tons   TOTAL VOLUME IMPACT = 658 FT^3

Figure 4.11 - Breakdown of MWF for addition of 100 KW to Electrical Load of SES2



DIRECT WEIGHTS = + 3.59 tons

INDIRECT WEIGHTS = - 2.95 tons

TOTAL WEIGHT IMPACT = + 0.64 tons   TOTAL VOLUME IMPACT = 2700 FT^3

Figure 4.12 - Breakdown of MWF for addition of 100 FT^2 to cushion area of SES2

CONCLUSIONS

(1) The ARCJ6 computer ship synthesis model worked exceedingly well for this thesis. Although the program is more complicated than HANDE (hydrofoil ship synthesis model) in terms of requiring more input by the user, the program does allow for a greater flexibility in specifying the level of detail desired. However, the Initialization module of HANDE was much less expensive to run than the ARCJ6 reflecting the added complexity of non-linear optimization for the SES perturbations.

(2) Marginal weight factors for Surface Effect Ships showed a linear increase with increasing displacement. A primary cause of the increase is believed to be the increasing range requirement of the baselines investigated.

(3) The individual effects predicted by marginal weight factors are additive and may be summed to determine the total impact of a subsystem.

(4) The SES is a weight sensitive ship as evidenced by the relative magnitude of the marginal weight factors for payload weight and space.

(5) Excess volume in an SES should be tolerated since any reduction in space without reducing the payload will cause the

ship's weight to increase.

CHAPTER 5.

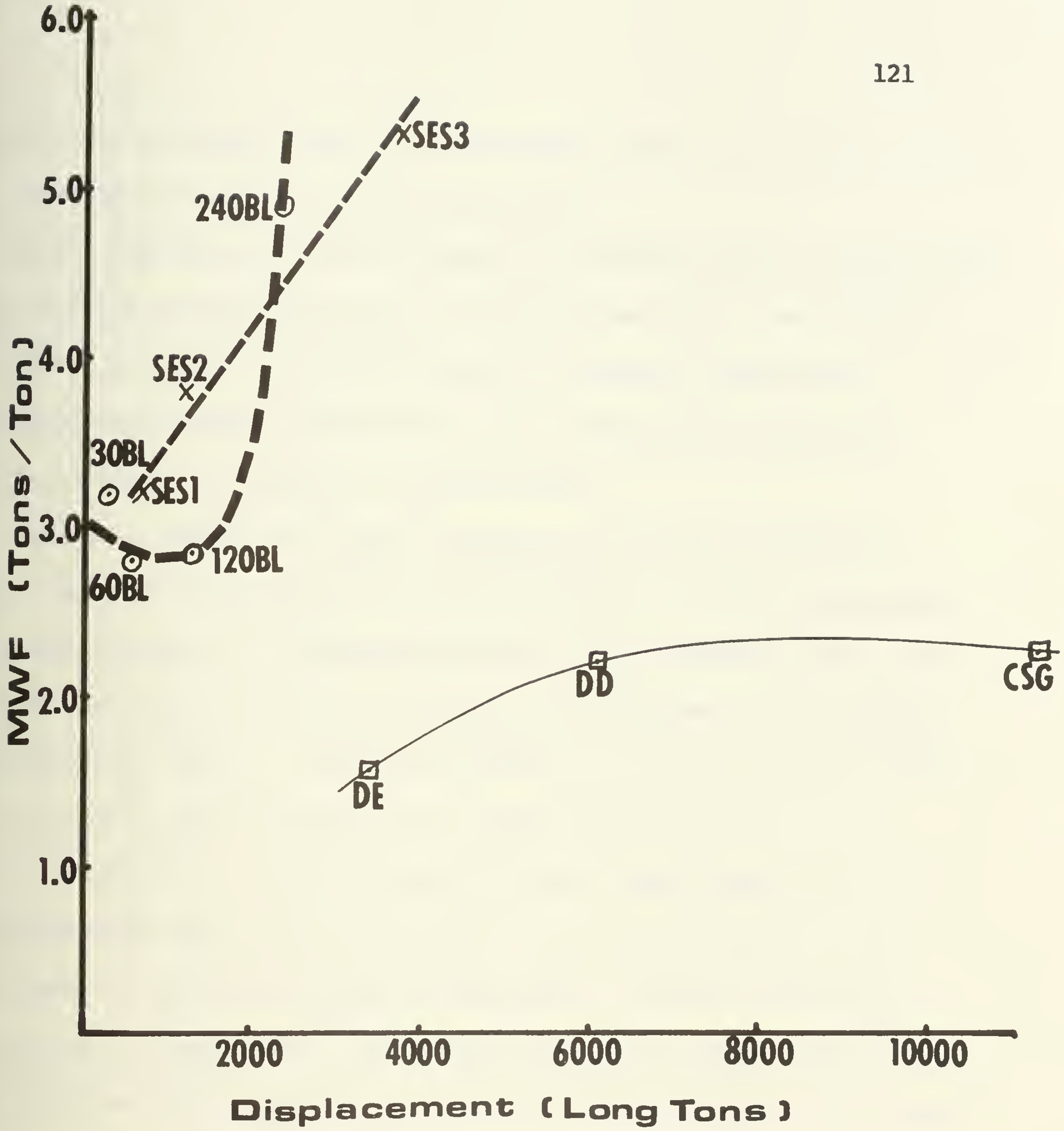
COMPARISON OF MARGINAL WEIGHT FACTORS

NTRODUCTION

This thesis has developed marginal factors for two high performance iips which are of current interest to the U. S. Navy. These factors, mputed for the four payload support areas of weight, manning, electric wer, and space required represent the sum of direct and indirect pacts of a subsystem on a ship's full load displacement. To evaluate e output, a comparison between the factors developed by this thesis for drofoils and surface effect ships and the factors developed by Howell eference 5) for conventional displacement vessels is presented. The asons for differences between the various ship types will be discussed d will cover those differences between the ship synthesis models that fect the size of the MWF as well as differences inherent in the dividual ship types. Finally, sample calculations for determining the tal impact of a subsystem are shown for each of the three ship types. ese calculations illustrate how the same subsystem can cause widely rying impacts on different ship types.

LOAD WEIGHT MWF

Figure 5.1 is a plot of the marginal weight factors of payload ight for hydrofoils, surface effect ships, and conventional displacement ips versus full load displacement. Since the computer ship synthesis dels for the high performance ships are not sensitive to payload weight



MWF For Weight
VS
Full Load Displacement
Figure 5.1

ocation, the mid-range values for displacement ships (i.e. weight at the ain deck) were chosen for comparison purposes.

First, the magnitude of the factors for payload weight is significantly igher for SES and hydrofoils than for displacement ships; and secondly, he factors for these high performance ships increase rapidly with ncreasing displacement but the factors for displacement ships react lowly and appear to approach a limiting value.

Table 5.1 presents the major components of the full load MWF of ayload weight for each ship type of approximately the same displacement. ne marginal factors for structural weight, fuel, propulsion plant weight, nd auxiliary weight are the most significant components of the payload eight marginal factors. Structural weight has a MWF of 1.33 on the SES3 nich is much larger than that of the 240BL hydrofoil (0.34) or the aseline DE (0.19). At first glance this might seem strange inasmuch as ne displacement ship with its steel hull has a lower structural MWF nan either of the two aluminium hulled vessels. However, the MWF for ructure on a displacement ship is much lower than that of a comparably zed high performance ship due to a basic difference between conventional splacement ships and an SES or a hydrofoil. Additional weight on a gh performance ship must be supported by a larger foil on a hydrofoil d by a larger cushion area or higher cushion pressure on an SES. For e SES, a larger cushion causes the structural weight to increase ereas the higher cushion pressure will increase the drag thus requiring re fuel and larger propulsion plants thus increasing the structural ight. For the hydrofoil, a larger foil increase the hydrodynamic drag

Table 5.1

MARGINAL WEIGHT FACTOR FOR PAYLOAD WEIGHT VARIATION

SHIP	SHIP		MARGINAL WEIGHT FACTORS (TONS/TON)					
NAME	DESCRIPTION	Δ FL	L.S.	GRP1	GRP2	FUEL	GRP5XX	GRP567
SES3	3800T-SES	5.56	3.97	1.33	0.41	1.59	0.21	- -
240BL	2600T-HYD	4.90	3.32	0.34	0.56	1.58	0.08	0.80
DE	3400T- DE	1.36	1.29	0.19	- -	0.07	- -	- -

hich will in turn increase the fuel and propulsion plant weight causing he ship to grow and the structural weight to increase. In contrast, isplacement ships support the additional payload weight by enlarging he ship's under water body (i.e. displacement). With a large displacement hip, only a relatively small increase in hydrodynamic drag occurs due to he increased wetted surface area and hence the MWF for structure and uel is small compared to those of the high performance ships.

It is surprising that the structural MWF is so large for the SES s compared to the hydrofoil and the displacement ship. The reason for his result is that the ARCJ6 synthesis model used for the SES supports he added payload weight by increasing the ship's cushion area rather than ubstantially increasing the cushion pressure. The SES's structure erves two purposes. First, the structure encloses the required volume; nd secondly, it provides the cushion area necessary to support the eight of the ship. This support function is quite similiar to the foil ystem of a hydrofoil. Therefore, a better comparison between hydrofoils nd the SES would be to sum the marginal factors for structure and T.GRP.567 since this would include the structural weight and the lift ystem for both ships. Having done this, we get a MWF for WT.GRP.100 + '.GRP.567 of 1.33 for the SES3 and 1.14 for the 240BL hydrofoil. ecause the SES is 50% larger than the hydrofoil being compared, it is elt that there is not a significant difference between the sum of the 'F for structure and the lift systems for high performance ships. lthough the SES does contain excess volume as compared to a hydrofoil

r displacement ship, this does not contribute to a higher MWF since emoving volume from an optimized SES design will increase the ship's isplacement.

As was discussed in Chapter 4, the ARCJ6 program did not provide for rubberized" lift engines; hence, the MWF for WT.GRP.567 for SES3 is zero. f the size of the lift engines were allowed to vary, the MWF for the SES ould have increased by approximately 0.15 which is not considered to be ignificantly different from those values reported.

The large MWF for fuel and propulsion plant weights for hydrofoils nd surface effect ships are a result of the rapid increase in the ydrodynamic drag by these high performance ships at their higher speeds. ne lower MWF of the conventional displacement ships reflect the smaller ncrease in hydrodynamic drag.

There is no apparent reason why the auxiliary weight (WT.GRP.5XX) aries between the three ship types and is thought to be due solely to ne differences in the weight estimating relationships of the models. NDE estimates WT.GRP.5XX as a function of internal volume and crew ze while ARCJ6 simply uses light ship weight to estimate auxiliary weight.

As can be noted in Figure 5.1, the high performance ships demonstrate sharply increasing full load MWF with increasing size. This trend is elt to mainly reflect the impact of an increasing range requirement on the aselines rather than simply being a function of the ship's size. As scussed in Chapter 3, the larger foil system and an increased fuel nsumption is also a factor in the trend for hydrofoils.

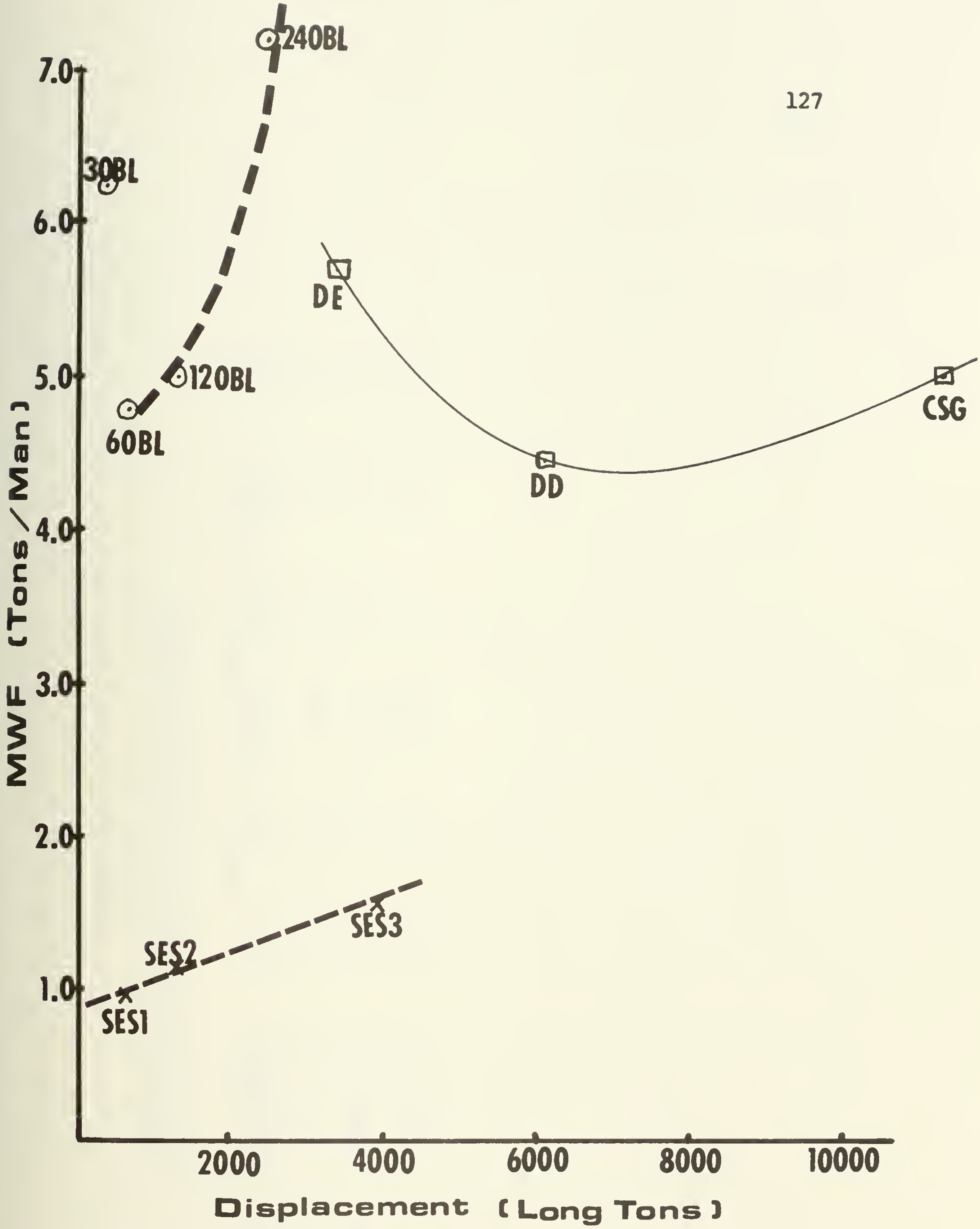
ANNING MWF

Figure 5.2 is a plot of the marginal weight factor for manning for ydrofoils, surface effect ships, and displacement ships versus the orresponding full load displacement. It is the change in enlisted manning hat was investigated since this is the parameter most likely to vary ith a payload as opposed to the number of officers or CPO's.

The full load displacement MWF for the SES is the lowest of the three hip types for reasons inherent in manning requirements as well as the urface effect ship type. Manning is a space intensive factor not having large weight impact on a design. Therefore, relative relationships in ize between the MWF for manning of the three ship types should be the me as the MWF for space. This was found to be true as can be seen in igure 5.4 and the reasons for the relative sizes of the MWF for manning n best be explained by studying the reasons for the relative sizes r space.

Table 5.2 presents a summary of the important components of the MWF r manning. Both the DE and the hydrofoil have equal marginal factors r light ship weight but the hydrofoil has a factor for fuel that is ur times as large as that of the DE's. This result is consistent with e marginal factor for payload weight discussed in the preceeding section this chapter. That is, weight has a much greater impact on a high rformance ship's drag and hence fuel and propulsion plant weight than i the case with displacement ships.

Note the low MWF for light ship weight on the SES3 and the corresponding



MWF For Enlisted Manning

VS

Full Load Displacement

Figure 5.2

Table 5.2

MARGINAL WEIGHT FACTOR FOR MANNING VARIATION

SHIP NAME	SHIP DESCRIPTION	Δ FL	MARGINAL WEIGHT FACTORS (TONS/MAN) L.S.	GRP1	GRP2	LOADS	FUEL
SES3	3800T-SES	1.60	0.72	0.38	0.12	0.41	0.46
240BL	2600T-HYD	7.20	4.49	0.89	0.31	0.39	2.30
DE	3400T- DE	5.70	4.60	2.45	- -	0.50	0.60

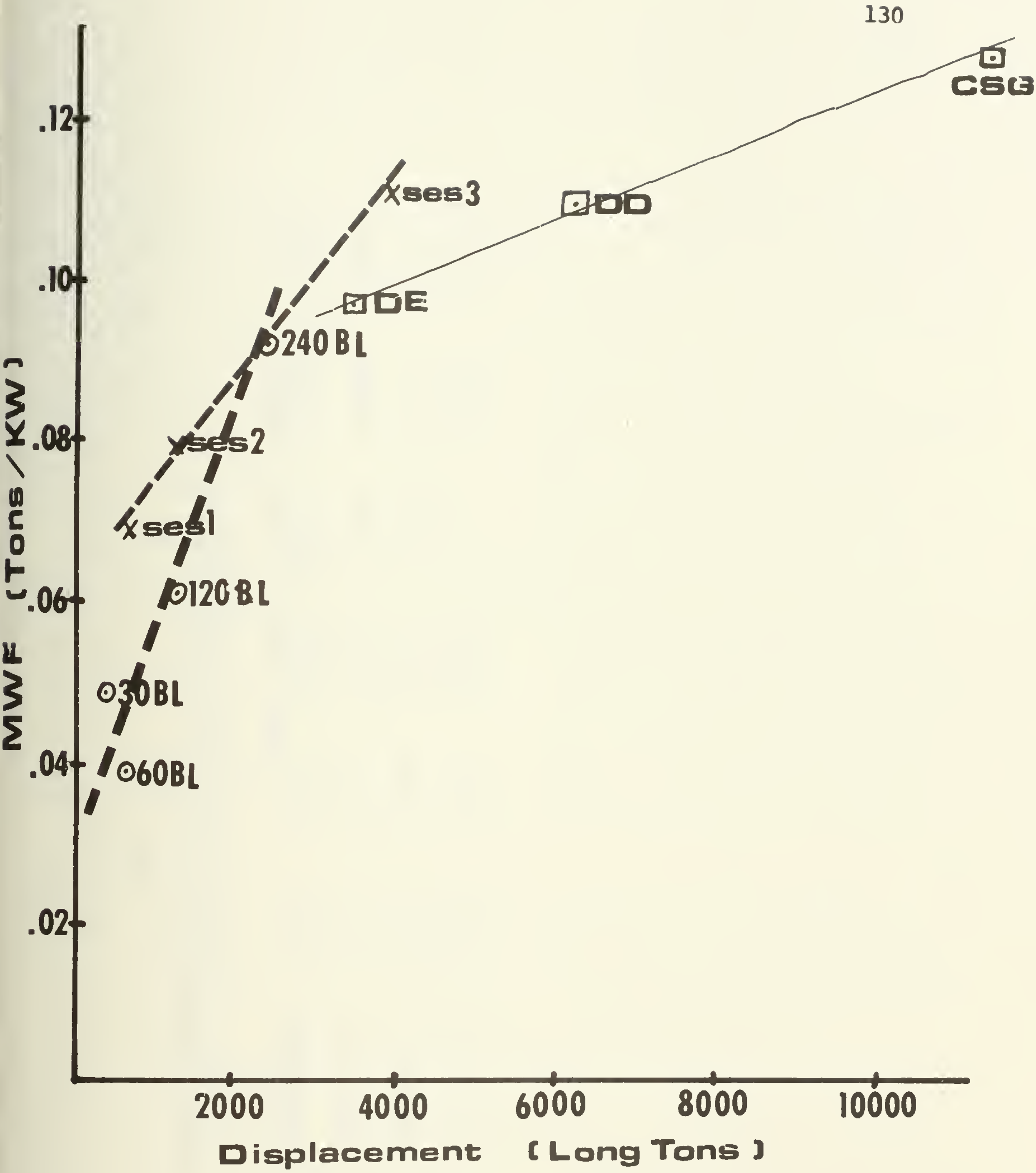
ow MWF for fuel. This small MWF is due to the low impact of space on the ES as compared with hydrofoils and displacement ships.

The "full loads" column in Table 5.2 indicates that all three ship ypes have essentially the same MWF for full loads. This implies that ach of the three ship synthesis models uses similiar weight estimating elationships for the full loads (e.g. water, provisions, and cargo) of the hips.

LECTRICAL POWER MWF

Figure 5.3 is a plot of the full load displacement MWF for electrical ower variation versus full load displacement for SES, hydrofoils, and isplacement ships. The factors for the high performance ships increase n a manner similiar to the payload weight factors since the same weight stimating relationship was used for the electrical plant weight (WT.GRP.300) y both HANDE and ARCJ6. The factors for the SES are slightly larger han a comparably sized hydrofoil although the difference is not felt to e significant.

The full load displacement MWF for electrical load variation on isplacement ships is larger than the high performance ships. This is n contrast to the situation discussed earlier for the MWF for payload eight. Table 5.3 illustrates that the MWF for WT.GRP.300 for the DE s three times larger than that of the hydrofoil or the SES. The reason or this difference is the weight estimating relationship used in the D07 computer ship synthesis model for displacement ships.



MWF For Electrical Load
VS
Full Load Displacement

Figure 5.3

Table 5.3

MARGINAL WEIGHT FACTOR FOR ELECTRICAL LOAD VARIATION

SHIP NAME	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/KW)					
		Δ FL	L.S.	GRP1	GRP2	FUEL	GRP3
SES3	3800T-SES	0.110	0.080	0.020	0.010	0.035	0.022
240BL	2600T-HYD	0.091	0.080	0.003	0.010	0.011	0.021
DE	3400T- DE	0.096	0.090	0.015	- -	0.005	0.067

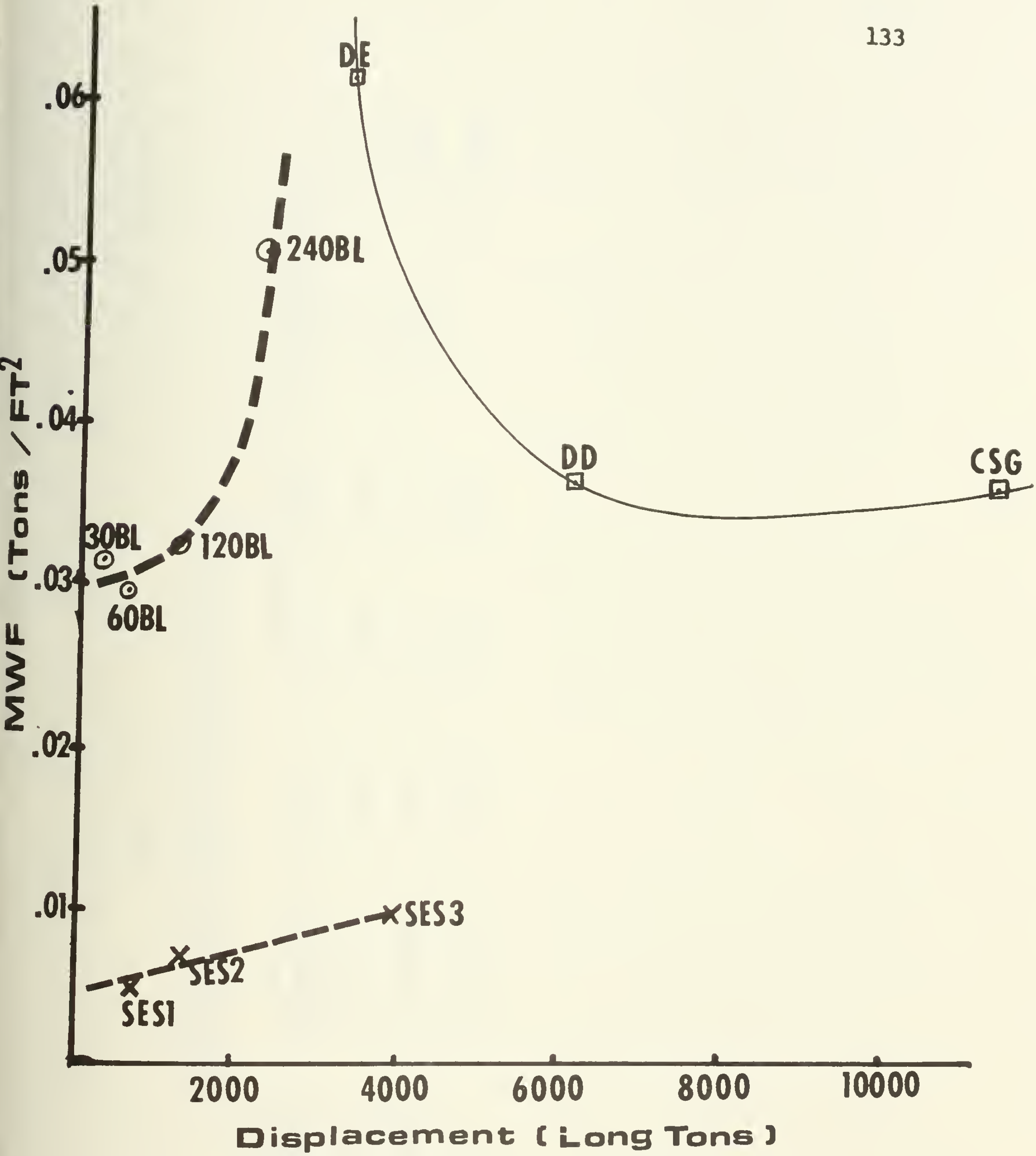
PACE MWF

Figure 5.4 is a plot of the full load displacement MWF for space for ydrofoils, surface effect ship, and displacements ships versus full load isplacement. The factors for the SES represent only the addition of space o the ship and not its removal. Examining the plot for trends, it is oted that the factors for SES increase slowly as the full load displacement ncreases; the factors for hydrofoils increase more sharply than those f the SES; and, the factors for conventional displacement ships present declining trend with increasing displacement.

As was discussed in Chapter 4, an SES reacts to either an increase r decrease in space by increasing the ship's full load displacement. The ow value of these factors for the SES is due to the counterbalancing of he increase in structural weight by a decrease in the propulsion plant ize and fuel weight.

Table 5.4 is a breakdown of the MWF for space variation and shows he important components of the full load MWF. Hydrofoils and displacement hips have similiarly sized factors although Table 5.4 illustrates that he reason is a balancing of components rather than each ship type eacting alike. The MWF for WT.GRP.100 is larger for displacement ships eflecting the use of steel in displacement ship's hulls in contrast to luminium in hydrofoils. Offsetting the larger structural MWF is the ize of the MWF's for fuel and propulsion plant weight of the hydrofoil hich is again a function of the increase in drag.

The SES has a large MWF for WT.GRP.100 relative to that of the



MWF For Space
VS
Full Load Displacement

Figure 5.4

Table 5.4

MARGINAL WEIGHT FACTOR FOR SPACE VARIATION

SHIP NAME	SHIP DESCRIPTION	Δ FL	MARGINAL WEIGHT FACTORS (TONS/FT^2) L.S.	GPP1	GPP2	FUEL
SES3	3800T-SES	0.0089	0.0390	0.0379	- 0.0110	- 0.0301
240BL	2600T-HYD	0.0500	0.0350	0.0140	+ 0.0040	+ 0.0150
DE	3400T- DE	0.0608	0.0564	0.0348	- - -	+ 0.0036

ydrofoil; however, as discussed in the payload weight section of this hapter, WT.GRP.100 for an SES contains weight used for the lifting unction while hydrofoils do not.

The slight increase in the full load displacement MWF for space on the ES as full load displacement increases, is a result of the increasing ange requirement for the baseline. Table 4.8 of Chapter 4 illustrates w the MWF for fuel varies from the 0.38 for the 500 ton SES to the 1.59 or the 3800 ton SES.

Hydrofoils exhibit a much more erratic variation in the full load splacement MWF for space than is the case for as SES. This lack of a rend within the hydrofoil data is felt to be due to the method the factors ere generated (combination of hand and computer calculations) rather an being due to the type of ship involved.

E OF MARGINAL WEIGHT FACTORS

Figures 5.5 and 5.6 illustrate the use of marginal weight factors to edict the total impact of two different subsystems on the three ship pes under discussion. As can be seen, the size of the impact varies th ship type and the values of the support parameters that describe e subsystem. For the "small weapon", the addition of the subsystem sults in the SES3 having the smallest total impact whereas, for the arge weapon", the destroyer escort receives the smallest total impact.

An important point illustrated by the two preceeding examples is that subsystem's impact on a vessel is not only a function of the type of ip involved that the equipment is to be installed on but also that the

EQUIPMENT ADDITION: SMALL WEAPON

SUPPORT REQUIREMENTS:

ADDITIONAL MANNING REQUIRED	=	2 Men
ADDITIONAL ELECTRIC LOAD	=	5 KW
EQUIPMENT WEIGHT	=	4 Tons
ADDITIONAL SPACE REQUIRED	=	315 Ft^2

SHIP	MANNING		KW LOAD		WEIGHT		SPACE		TOTAL
NAME	MWF	CHANGE	MWF	CHANGE	MWF	CHANGE	MWF	CHANGE	IMPACT
SES3	1.6	3.2	0.011	0.55	5.56	22.24	0.0089	2.80	28.79
240BL	7.2	14.4	0.091	0.46	4.90	19.6	0.050	15.75	50.21
DE	5.7	11.4	0.096	0.48	1.52	6.08	0.061	19.15	37.11

Figure 5.5

ADDITION OF A SMALL PAYLOAD TO THREE SHIP TYPES

EQUIPMENT ADDITION: LARGE WEAPON

SUPPORT REQUIREMENTS:

ADDITIONAL MANNING REQUIRED = 4 Men

ADDITIONAL ELECTRICAL LOAD = 5 KW

EQUIPMENT WEIGHT = 61 Tons

ADDITIONAL SPACE REQUIRED = 900 Ft^2

SHIP	MANNING		KW LOAD		WEIGHT		SPACE		TOTAL
NAME	MWF	CHANGE	MWF	CHANGE	MWF	CHANGE	MWF	CHANGE	IMPACT
SES3	1.6	6.4	0.011	0.52	5.56	339.16	0.0089	8.01	354.09
240BL	7.2	28,8	0.091	4.28	4.90	298.90	0.050	45.00	376.98
DE	5.7	22.8	0.096	4.51	1.52	92.72	0.061	54.72	174.75

Figure 5.6

ADDITION OF A LARGE PAYLOAD TO THREE SHIP TYPES

size of the support parameters is crucial. This is true because the relative magnitude of the MWF's for the four payload support parameters varies with the ship type. The conclusion is that the subsystem designer can adjust the support parameters of his design to produce a product with minimum impact on each of the various ship types.

LUSIONS

1. The MWF for payload weight for hydrofoils and surface effect ships are of similiar magnitude and sharply increase with increasing ship displacement. The size of the factors for high performance ships is significantly larger than those of conventional displacement ships.

2. The MWF for Manning for displacement ships and hydrofoils are of similiar magnitude whereas the MWF for SES is significantly smaller. The trends for each of the ship types match those of the MWF for Space.

3. The MWF for Space tend to increase with increasing displacement for high performance ships and the factors for displacement ships decrease slightly. The size of the factors for hydrofoils and displacement ships are similiar whereas those factors for the SES are much smaller.

4. MWF's for Electrical Power increase with increasing displacement irregardless of ship type.

5. A subsystem's impact on a specific ship is a function of the ship type, the ship's size, and the relative size of the support parameters that describe the subsystem.

Chapter 6.

CONCLUSIONS AND RECOMMENDATIONS

ONCLUSIONS

This thesis has investigated the component and ship development equences for several of the U.S. Navy's newest combatant ships. In ddition, the subsystem selection/design process was studied to determine urrent procedures within the ship design community that would account or the recent growth in the growth in ship acquisition costs due to he increasing impact of subsystems. The following conclusions are ade with regard to the efforts discussed above:

(1) Off-the-shelf subsystems are selected by Ship Acquisition Managers to minimize the technical risk of the total ship system. Therefore, since major subsystems are commonly developed years prior to the ship on which the subsystem will be utilized, the Ship Acquisition Manager has no impact on a subsystem's physical characteristics.

(2) The Subsystem Acquisition Manager develops equipments many years earlier than the host ship and, therefore, has little information available to assist him in determining optimum physical characteristics for the subsystem.

(3) Because Subsystem Acquisition Managers have a limited background in naval architecture, tools such as Marginal Cost Factors are essential to assist Subsystem Designers

in minimizing the ship-impact costs of their product.

To aid Subsystem Designers in assessing the ship-impact costs of a ubsystem as well as to provide the Ship Acquisition Managers with a tool or conducting tradeoff analyses, the remainder of this thesis was evoted to developing Marginal Weight Factors for Hydrofoils and Surface ffect Ships. These factors are intended to complement factors previously eveloped for conventional displacement ships. The following conclusions re made with regard to the factors developed for these high performance hips:

(1) A subsystem's impact on a specific ship is a function of the ship type, the ship's size, and the relative size of the various support parameters that describe the subsystem.

(2) In general, the Marginal Weight Factors for high performance ships are larger than those of comparably sized conventional displacement ships. A significant exception is the lower MWF for Space on Surface Effect Ships and Hydrofoils indicating that these high performance ships are relatively insensitive to changes in required space.

(3) For the specific baseline ships investigated, the Marginal Weight Factors for all four payload support parameters tended to increase with increasing ship size.

RECOMMENDATIONS

During the process of developing data for this thesis, it was found hat several areas could not be adequately covered due to time and unding limitations. If further work in the area of Marginal Weight actors for high performance ships is undertaken, the following ecommendations for additional study are suggested:

(1) Development of Marginal Weight Factors for Small Waterplane Area Twin Hull (SWATH) ships.

(2) Use of the Synthesis section of HANDE to investigate the linearity limits for the MWF's of Hydrofoils.

(3) Use of ARCJ6 to investigate the linearity limits for the MWF's of Surface Effect Ships.

(4) Preparation of Marginal Cost Factors as cost models for high performance ships become available and accepted.

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APPENDIX I

Tables of Data

for

Conventional Displacement Ships

SHIP NO.	SHIP DESCRITPION	MARGINAL WEIGHT FACTORS (TONS/TON)					
		Δ_{FL}	L.S.	GRP.1	GRP.2	GRP.5	FUEL
1	BASELINE DE	1.36	1.29	0.19			0.07
2	STEAM DE-SPEED	1.90	1.70	0.34	0.16	0.06	0.18
10	BASELINE DD	2.19	2.08	0.66	0.108		0.108
12	BASELINE CSG	2.30	2.11	0.71		0.12	0.19
14	NUC. CRUISER	1.91	1.93	0.62	0.04	0.05	

TABLE I.1 - MARGINAL FACTOR FOR WEIGHT VARIATION

TWENTY FEET BELOW THE MAIN DECK

SHIP NO.	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/TON)					
		Δ_{FL}	L.S.	GRP.1	GRP.2	GRP.5	FUEL
1	BASELINE DE	1.57	1.47	0.32		0.03	0.10
2	STEAM DE-SPEED	2.24	1.98	0.40	0.30	0.08	0.24
10	BASELINE DD	2.20	2.08	0.66	0.084		0.12
12	BASELINE CSG	2.26	2.07	0.69		0.10	0.18
14	NUC. CRUISER	1.93	1.93	0.62	0.03	0.06	

TABLE I.2 - MARGINAL FACTOR FOR WEIGHT VARIATION

AT THE MAIN DECK

SHIP NO.	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/TON)					
			L.S.	GRP.1	GRP.2	GRP.5	FUEL
1	BASELINE DE	1.94	1.81	0.55		0.09	0.12
2	STEAM DE-SPEED	3.00	2.62	0.68	0.52	0.16	0.32
10	BASELINE DD	2.22	2.09	0.70		0.10	0.12
12	BASELINE CSG	2.14	1.98	0.65		0.10	0.15
14	NUC. CRUISER	1.97	1.97	0.63	0.01	0.09	

TABLE I.3 - MARGINAL WEIGHT FACTOR FOR WEIGHT VARIATION

FORTY FEET ABOVE THE MAIN DECK

SHIP NO.	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/MAN)					
		Δ_{FL}	L.S.	GRP.1	GRP.5	GRP.6	FUEL
1	BASELINE DE	5.70	4.60	2.45	0.70	0.85	0.60
2	STEAM DE-SPEED	3.70	2.95	1.60	0.50	0.70	0.25
3	STEAM DE-POWER	4.35	3.45	1.70	0.55	0.75	0.40
4	SMALL C_x DE	5.50	4.30	2.25	0.70	0.80	1.05
5	LARGE C_x DE	5.30	4.15	2.15	0.70	0.80	0.60
6	SMALL C_p DE	6.35	5.20	2.90	0.80	0.90	0.70
7	LARGE C_p DE	5.95	4.85	2.65	0.80	0.85	0.60
8	LARGE CREW DE	5.55	4.40	2.35	0.75	0.80	0.60
9	DE HAB.-STD.	6.40	5.20	2.85	0.85	0.90	0.70
10	BASELINE DD	4.45	3.60	1.65	0.60	0.70	0.30
11	DD HAB.-STD.	5.20	4.25	2.10	0.75	0.85	
12	BASELINE CSG	5.05	3.85	1.85	0.65	0.75	0.55
13	CSG HAB.-STD.	6.35	5.10	2.40	0.95	0.95	0.60
14	NUC. CRUISER	4.60	4.00	1.95	0.75	0.85	

TABLE I.4 - MARGINAL WEIGHT FACTORS FOR MANNING VARIATION

SHIP NO.	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/KW)					
		Δ_{FL}	L.S.	GRP.1	GRP.3	GRP.5	FUEL
1	BASELINE DE	0.096	0.090	0.015	0.067		0.005
2	STEAM DE-SPEED	0.148	0.134	0.037	0.067	0.008	0.013
3	STEAM DE-POWER	0.124	0.111	0.029	0.066	0.005	0.012
4	SMALL C_x DE	0.105	0.100	0.020	0.068	0.002	0.006
5	LARGE C_x DE	0.102	0.095	0.017	0.068	0.002	0.008
6	SMALL C_p DE	0.110	0.106	0.025	0.069	0.003	0.006
7	LARGE C_p DE	0.117	0.109	0.027	0.069	0.004	0.007
8	LARGE CREW DE	0.101	0.101	0.021	0.069	0.003	
9	DE HAB.-STD.	0.110	0.102	0.022	0.068	0.003	0.008
10	BASELINE DD	0.109	0.104	0.031	0.051		0.004
12	BASELINE CSG	0.128	0.115	0.039	0.055	0.006	0.011
13	CSG HAB.-STD.	0.132	0.123	0.041	0.055	0.009	0.010

TABLE I.5 - MARGINAL WEIGHT FACTORS FOR ELECTRICAL LOAD VARIATION

SHIP NO.	SHIP DESCRIPTION	MARGINAL WEIGHT FACTORS (TONS/FT.^{2}) Δ_{FL}	L.S.	GRP.1	GRP.2	GRP.5	GRP.6	FUEL
1	BASELINE DE	.0608	.0564	.0348		.0104	.0052	.0036
2	STEAM DE-SPEED	.0260	.0276	.0220	-.0076	.0064	.0036	-.0008
3	STEAM DE-POWER	.0460	.0428	.0248	.0012	.0084	.0036	.0028
4	SMALL C_x DE	.0614	.0572	.0350	.0008	.0106	.0048	.0042
5	LARGE C_x DE	.0576	.0548	.0334	.0006	.0104	.0048	.0028
6	SMALL C_p DE	.0664	.0610	.0378	.0012	.0108	.0050	.0056
7	LARGE C_p DE	.0542	.0518	.0310	.0006	.0100	.0048	.0024
8	LARGE CREW DE	.0594	.0556	.0340	.0008	.0104	.0048	.0038
9	DE HAB.-STD.	.0588	.0550	.0336	.0006	.0102	.0048	.0038
10	BASELINE DD	.0360	.0340	.0180		.0080	.0032	.0020
12	BASELINE CSG	.0362	.0326	.0176	.0016	.0070	.0030	.0030
13	CSG HAB.-STD.	.0478	.0440	.0214	.0024	.0092	.0052	.0040
14	NUC. CRUISER	.0374	.0374	.0186	.0004	.0090	.0052	

TABLE I.6 - MARGINAL WEIGHT FACTOR FOR SPACE VARIATION

APPENDIX II

A. HANDE Initialization Module

B. Tables of Data for Hydrofoils

II.A HANDE Initialization Module

INTRODUCTION

The primary functions of the Initialization Module are to estimate ship size and to prepare data for use in the HANDE Synthesis section if so desired. The Initialization module accomplishes its functions by checking data provided by the designer for completeness and by calculating approximate ship configuration data. The output from Initialization may be sufficient to conduct high level tradeoff studies. However, only the major ship elements are considered by this module.

The design calculations of the Initialization Module include the areas of hull geometry, hydrodynamics, propulsion, weights, and performance. The calculations are based on empirical and approximate theoretical methods. An iterative process is used to ensure that the newly developed hydrofoil design will meet specified performance and mission requirements.

DESCRIPTION

A detailed flow chart for the Initialization Module is shown in Figure II.A.1. The sequence is briefly described below.

(1) Following data checking, the characteristics of a reference hull are calculated.

(2) The Military Payload Weight is an input to the program. The iteration parameters are set in preparation for the main sizing calculations. This includes an estimation of ship

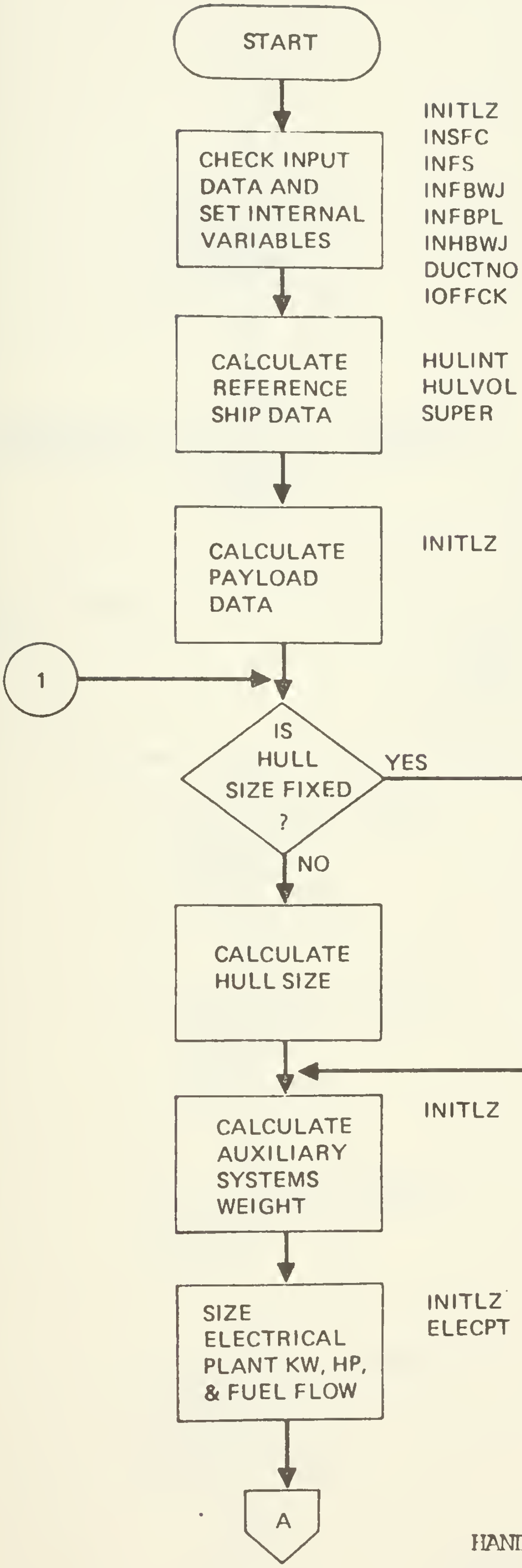

Figure II.A.1

HANDF Initialization Module

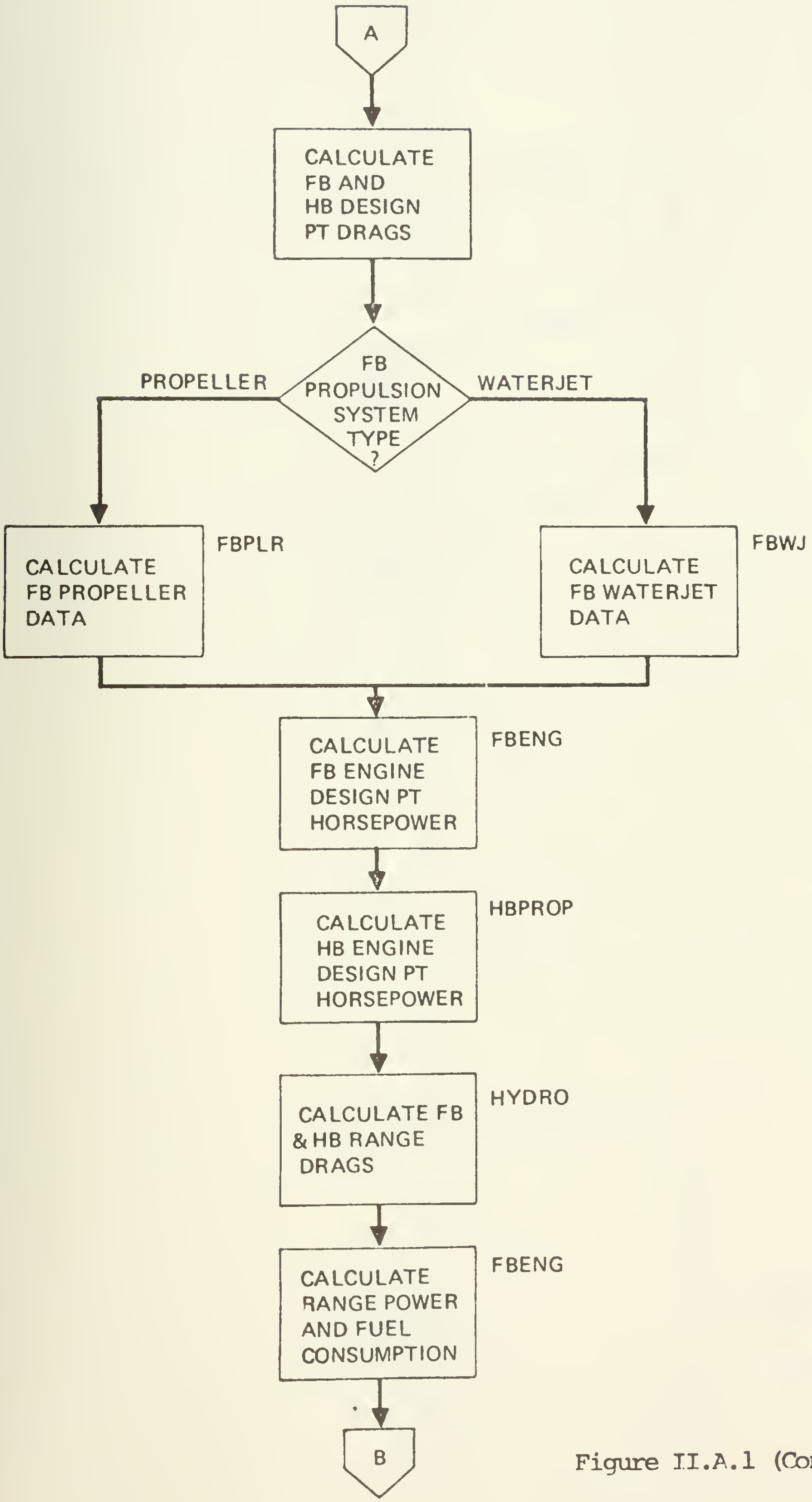

Figure II.A.1 (Continued)

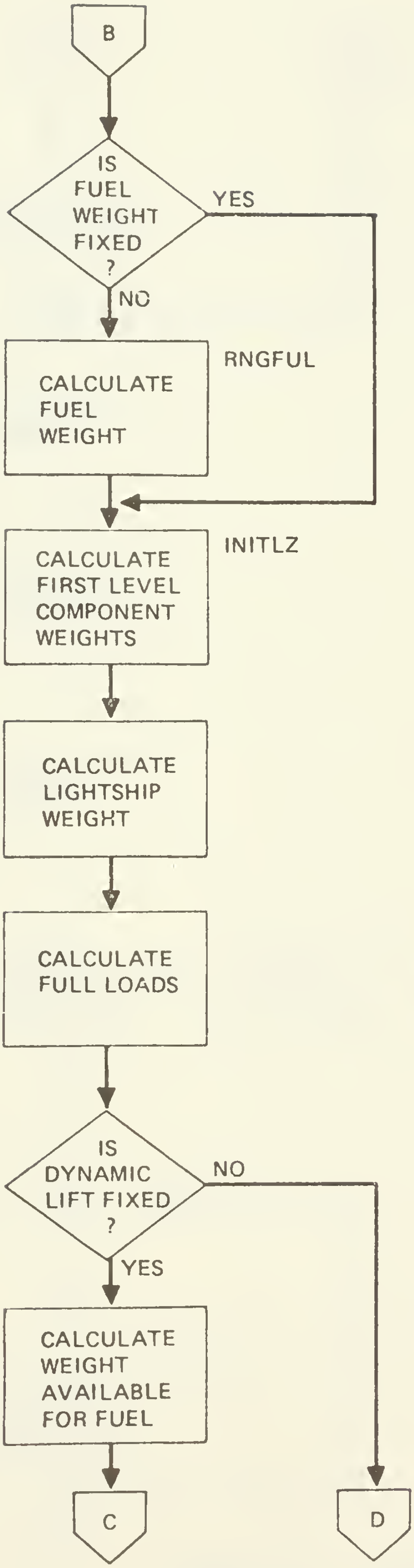

Figure II.A.1

(Continued)

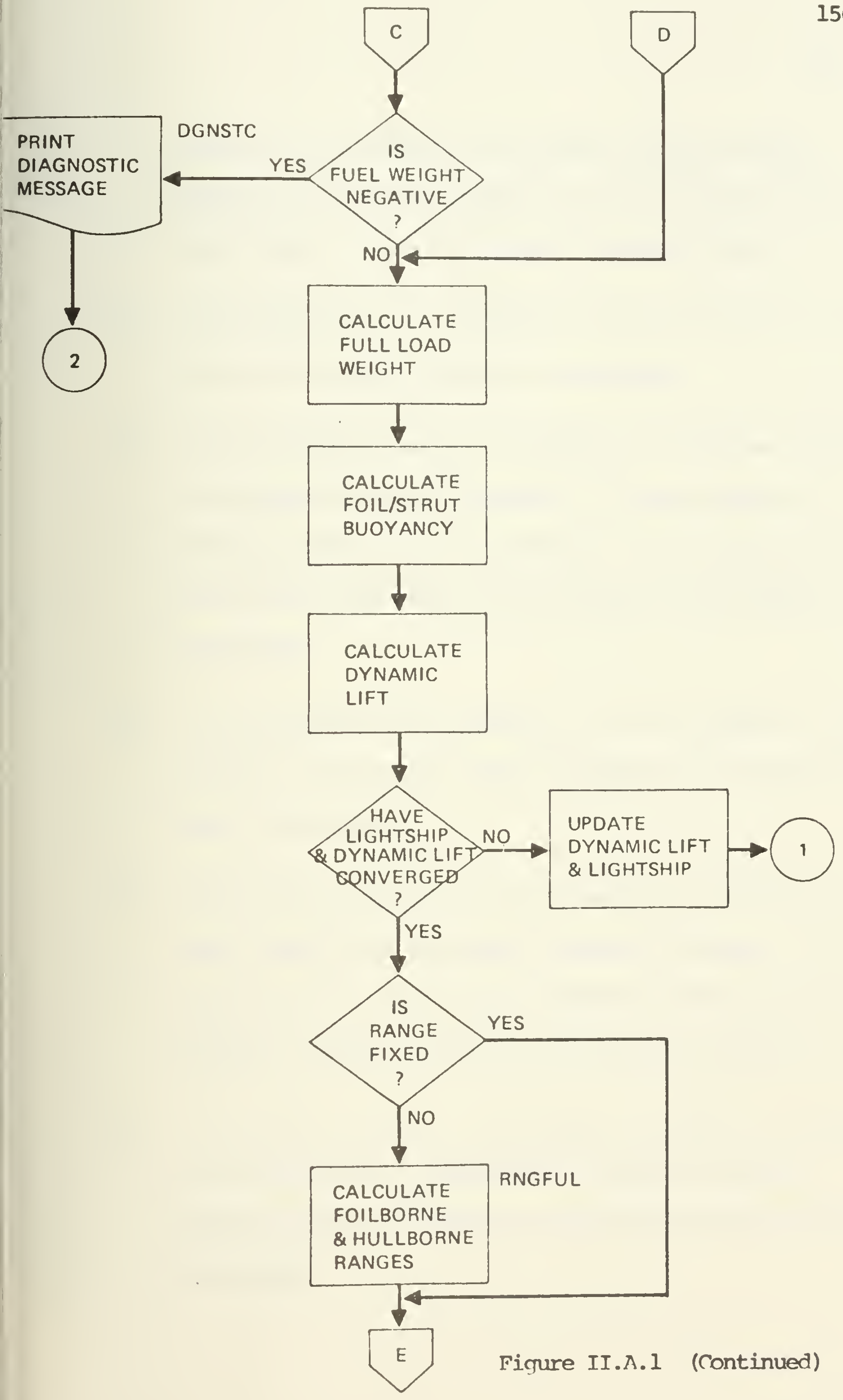

Figure II.A.1 (Continued)

weight if the designer has selected the mode wherein dynamic lift and fuel weight are to be calculated for a given range. At this point the iteration begins.

(3) If the designer has not elected to fix the ship size, the hull and deck house sizes are calculated.

(4) The hydrodynamic drag is calculated for both the foilborne and hullborne propulsion systems. Either waterjet or propeller systems may be considered. The drag, power and specific fuel consumption at the given range speeds are calculated.

(5) If the designer has not elected to fix the weight of fuel available, the weight of fuel required for the specified range is calculated.

(6) The weights of various ship components are calculated to the first level of the Ship Work Breakdown Structure. These include hull and deck house, propulsion and electric plants, auxiliary systems, outfit and furnishings, and weight margins.

(7) The lightship weight is calculated by summing the weights of the various ship components. The full loads are calculated from the ammunition and crew related items and fuel weight.

(8) If the designer has selected the mode which fixed dynamic lift, the weight of fuel available is calculated. The full loads are recalculated using this updated fuel weight.

(9) The full load weight, foil/strut buoyancy, and dynamic lift are then calculated. This concludes the calculations of the design iteration loop.

The dynamic lift and lightship weight are checked from iteration to iteration. When no significant changes in these two parameters occur in two successive iterations, the design has converged and the following calculations are made.

(a) If range is not fixed by the designer, the range is calculated for foilborne and hullborne operating conditions.

(b) Foil/Strut system parameters are calculated in accordance with the designers option.

(c) The volume required is calculated based on ship weight, mission duration, horsepower required, payload items, and crew size.

(d) The output as specified by the designer is printed.

A summary of the weight estimating relationships used by the HANDF Initializatin Module is provided below:

(1) WG.100 = f (Total Ship Volume)

(2) WG.200 = f (Required Horse Power)

(3) WG.300 = f (Installed KW)

(4) WG.400 = f (Total Ship Volume) + Fixed Navigation Weight + Input Military Payload.

(5) WG.5XX = f (Total Ship Volume, Crew Size)

(6) WG.567 = f (Full Load Dynamic Lift)

(7) WG.600 = f (Total Ship Volume, Crew Size)

(8) WG.700 = Designer's Input

(9) CREW & EFFECTS = f (Crew Size)

(10) AMMUNITION = Designer's Input

(11) PROVISIONS = f (Crew Size, Mission Duration)

(12) FRESH WATER = f (Crew Size)

(13) FUEL = f (Required Range, Speed, Engine Characteristics)

ACCURACY OF INITIALIZATION MODULE

A key question that had to be settled was, "What is the accuracy of the ship design produced by the Initialization compared to the weight of the ship produced by the Synthesis Module"? Due to the level of detail addressed by the Synthesis section, it is felt that the Synthesis output should be judged "correct" and any deviations be adjudged an "error".

To investigate the accuracy of the Initialization Module, three of the hydrofoil baselines used for this thesis were subjected to perturbations in cargo weight. The baselines were then redesigned using both the Initialization Module and the Synthesis Section. The output from HANDE is shown in Tables II.A.1, II.A.2, and II.A.3.

The results indicate that for the 300 ton hydrofoil (30BL), Initialization overestimates the full load displacement by 15 tons or is in error by +5%. For the 1300 ton hydrofoil (120BL), Initialization underestimated the full load displacement by 67 tons or is in error by -5%. Finally, for the 2600 ton vehicle (240BL), Initialization underestimates the full load displacement by 348 tons or is in error by -12%. Because the Initialization Module uses linear parametric relations, the results described above shoud be expected since the actual values can vary on either side of the linearization. In addition, HANDE was developed to design hydrofoils with displacements below 3000 tons; therefore, the largest errors can be expected as designs approach this point.

Although it was determined that Initialization provides a reasonably

Table II.A.1

30RL HYDROFOIL CARGO WEIGHT VARIATION

	BASELINE VALUES		ERROR	+ 7.5 TONS CARGO WEIGHT				
	SYNTHESIS VALUE	INITIALIZATION VALUE		SYNTHESIS NEW	SYNTHESIS DIFF	INITIALIZATION NEW	INITIALIZATION DIFF	ERROR IN DIFF
FULL LOAD DISP	298.2	313.9	+ 15.7	311.0	+12.8	326.2	+ 12.3	- 0.5
WT.GRP.100	53.9	50.7	- 3.2	54.1	+ 0.2	50.7	0.0	- 0.2
WT.GRP.200	25.2	31.7	+ 6.5	26.2	+ 1.0	32.6	+ 0.9	0.0
WT.GRP.300	8.6	8.6	0.0	8.7	+ 0.1	8.7	+ 0.1	0.0
WT.GRP.400	11.4	11.4	0.0	11.4	0.0	11.4	0.0	0.0
WT.GRP.5XX	17.2	17.2	0.0	17.3	+ 0.1	17.3	+ 0.1	0.0
WT.GRP.567	34.9	43.0	+ 8.1	35.8	+ 0.9	44.7	+ 1.7	+ 0.8
WT.GRP.600	18.3	18.3	0.0	18.4	+ 0.1	18.4	+ 0.1	0.0
WT.GRP.700	9.5	9.5	0.0	9.5	0.0	9.5	0.0	0.0
LIGHT SHIP	205.9	219.0	+ 13.1	208.4	+ 2.5	222.1	+ 3.1	+ 0.6
FUEL	71.9	74.5	+ 2.6	74.7	+ 2.8	76.3	+ 1.8	- 1.0

Table II.A.2

120BL HYDROFOIL CARGO WEIGHT VARIATION

	BASELINE VALUES			+ 30 TONS CARGO WEIGHT				
	SYNTHESIS VALUE	INITIALIZATION VALUE	ERROR	SYNTHESIS NEW	SYNTHESIS DIFF	INITIALIZATION NEW	INITIALIZATION DIFF	ERROR IN DIFF
FULL LOAD DISP	1349.9	1281.9	-68.0	1423.3	+73.4	1356.4	+74.5	+ 1.1
WT.GRP.100	208.3	191.3	-17.0	210.3	+ 2.0	197.2	+ 5.9	+ 3.9
WT.GRP.200	109.8	90.8	-19.0	117.1	+ 7.3	94.7	+ 3.9	- 3.4
WT.GRP.300	22.9	22.7	- 0.2	22.9	0.0	22.9	+ 0.2	+ 0.2
WT.GRP.400	59.3	59.1	- 0.2	59.3	0.0	59.3	+ 0.2	+ 0.2
WT.GRP.5XX	93.5	91.5	- 2.0	93.5	0.0	93.5	+ 2.0	+ 2.0
WT.GRP.567	175.7	177.1	+ 1.4	187.2	+11.5	187.3	+10.2	- 1.3
WT.GRP.600	74.2	72.9	- 1.3	74.2	0.0	74.2	+ 1.3	+ 1.3
WT.GRP.700	22.0	22.0	0.0	22.0	0.0	22.0	0.0	0.0
LIGHT SHIP	880.4	836.4	-44.0	904.4	+24.0	863.5	+27.1	+ 3.1
FUEL	389.1	365.2	-23.9	408.5	+19.4	382.5	+17.3	- 2.1

Table II.A.3

240BL HYDROFOIL CARGO WEIGHT VARIATION

	BASELINE VALUES			+ 120 TONS CARGO WEIGHT				
	SYNTHESIS VALUE	INITIALIZATION VALUE	ERROR	SYNTHESIS NEW	SYNTHESIS DIFF	INITIALIZATION NEW	INITIALIZATION DIFF	ERROR IN DIFF
FULL LOAD DISP	2617.8	2425.5	-192.3	3067.3	+449.5	2719.5	+294.0	-155.5
WT.GRP.100	318.1	328.0	+ 9.9	332.7	+ 14.6	335.2	+ 7.2	- 7.4
WT.GRP.200	239.5	155.2	- 84.3	300.2	+ 60.7	173.3	+ 18.1	- 42.6
WT.GRP.300	33.1	32.9	- 0.2	33.1	0.0	33.1	+ 0.2	+ 0.2
WT.GRP.400	67.8	67.5	- 0.3	67.8	0.0	67.8	+ 0.3	+ 0.3
WT.GRP.5XX	167.4	164.7	- 2.7	167.4	0.0	167.4	+ 2.7	+ 2.7
WT.GRP.567	342.9	332.3	- 10.6	422.8	+ 79.9	371.1	+ 38.8	- 41.1
WT.GRP.600	125.1	123.5	- 1.6	125.1	0.0	125.1	+ 1.6	+ 1.6
WT.GRP.700	75.6	75.6	0.0	75.6	0.0	75.6	0.0	0.0
LIGHT SHIP	1574.8	1471.6	-103.2	1753.3	+178.5	1550.8	+ 79.2	- 99.3
FUEL	877.2	788.1	- 89.1	1028.1	+150.9	882.8	+ 94.7	- 56.2

accurate full load displacement and corresponding weight group summary, a question still remained as to whether or not Initialization was suitable for generating marginal weight factors. That is, even though the weights produced by Initialization are accurate, "Is the difference between the baseline values and the perturbation due to the addition of cargo weight produced by Initialization, accurate when compared to a similiar change produced by Synthesis"? The column labeled "ERROR IN DIFF." in Tables II.A.1, II.A.2, and II.A.3 attempts to answer this question.

As discussed in Chapter 2, marginal weight factors are determined by dividing the net change in weight by the amount that the support parameter is varied. Table II.A.4 provides a summary of the marginal weight factors for the three baselines for cargo weight variation.

Table II.A.4

MWF for Cargo Weight Variation

SHIP	SYNTHESIS MWF	INITIALIZATION MWF	ERROR	% ERROR
30BL	1.71	1.64	- 0.07	- 4 %
120BL	2.45	2.48	+ 0.03	+ 1 %
240BL	3.75	2.45	- 1.30	-35 %

The Initialization Module of HANDE does give accurate results for hydrofoil designs below 1500 tons. Above this displacement, however, Initialization's accuracy becomes increasingly poor as the ship's size approaches 3000 tons. Initialization tends to underestimate WT.GRP.100,

WT.GRP.200, WT.GRP.567, and the FUEL required as the size of the Hydrofoil increases.

Table II.B.1

Payload Weight Variations for 30BL Hydrofoil

	BASELINE	+ 5 TONS		+ 10 TONS		- 5 TONS		- 8.5 TONS	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF	NEW	DIFF	NEW	DIFF
LBP	129.0	129.8	+ 0.8	130.5	+ 1.5	128.8	- 0.2	128.1	- 0.9
FULL LOAD DISP.	313.9	330.0	+16.1	345.8	+31.9	300.1	-13.8	288.1	-25.8
WT.GRP.100	50.7	51.6	+ 0.9	52.5	+ 1.8	50.5	- 0.2	49.7	- 1.0
WT.GRP.200	31.7	33.1	+ 1.4	34.4	+ 2.7	30.5	- 1.2	29.5	- 2.2
WT.GRP.300	8.6	9.4	+ 0.8	10.1	+ 1.5	7.9	- 0.7	7.3	- 1.3
WT.GRP.400	11.4	11.4	0.0	11.4	0.0	11.3	- 0.1	11.3	- 0.1
WT.GRP.5XX	17.2	17.5	+ 0.3	17.7	+ 0.5	17.2	0.0	17.0	- 0.2
WT.GRP.567	43.0	45.2	+ 2.2	47.4	+ 4.4	41.1	- 1.9	39.4	- 3.6
WT.GRP.600	18.3	18.5	+ 0.2	18.7	+ 0.4	18.3	0.0	18.1	- 0.2
WT.GRP.700	9.5	14.5	+ 5.0	19.5	+10.0	4.5	- 5.0	1.0	- 8.5
LIGHT SHIP	219.0	231.4	+12.4	243.5	+24.5	208.5	-10.5	199.3	-19.7
FUEL	74.5	78.2	+ 3.7	81.9	+ 7.2	71.3	- 3.2	68.5	- 6.0
ACT.TOTAL VOL.	46083	46948	+ 865	47722	+1639	45910	- 173	45174	- 909
REQ.TOTAL VOL.	46196	46987	+791	47746	+1550	45503	- 693	44903	-1293

Table II.B.2

Enlisted Manning Variations for 30BL Hydrofoil

CHARACTERISTICS	BASELINE	+ 5 MEN		+ 10 MEN		- 2 MEN		- 5 MEN	
	VALUES	NEW	DIFF	NEW	DIFF	NEW	DIFF	NEW	DIFF
LBP	129.0	132.0	+ 3.0	134.7	+ 4.7	127.9	- 1.1	125.8	- 3.2
FULL LOAD DISP.	313.9	345.2	+31.3	372.6	+58.7	300.5	-13.4	281.5	-32.4
WT.GRP.100	50.7	54.3	+ 3.6	57.8	+ 7.1	49.4	- 1.3	47.0	- 3.7
WT.GRP.200	31.7	34.2	+ 2.5	36.3	+ 4.6	30.7	- 1.0	29.1	- 2.6
WT.GRP.300	8.6	9.4	+ 0.8	10.0	+ 1.4	8.4	- 0.2	8.0	- 0.6
WT.GRP.400	11.4	11.5	+ 0.1	11.6	+ 0.2	11.3	- 0.1	11.2	- 0.2
WT.GRP.5XX	17.2	22.5	+ 5.3	26.9	+ 9.7	15.6	- 1.6	13.3	- 3.9
WT.GRP.567	43.0	47.3	+ 4.3	51.1	+ 8.1	41.1	- 1.9	38.5	- 4.5
WT.GRP.600	18.3	21.5	+ 3.2	24.0	+ 6.3	16.1	- 2.2	13.3	- 5.0
WT.GRP.700	9.5	9.5	0.0	9.5	0.0	9.5	0.0	9.5	0.0
LIGHT SHIP	219.0	241.7	+22.7	261.3	+42.3	209.3	- 9.7	195.6	-23.4
FUEL	74.5	81.7	+ 7.2	88.0	+14.5	71.4	- 3.1	67.0	- 7.5
ACT.TOTAL VOL.	46083	49400	+3317	52553	+6470	44926	-1157	42721	-3362
REQ.TOTAL VOL.	46196	49440	+3244	52394	+6198	44835	-1361	42788	-3408

Table II.B.3

Electrical Load Variations for 30BL Hydrofoil

	BASELINE	+ 100 KW		+ 200 KW	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF
LBP	129.0	129.1	+ 0.1	129.1	+ 0.1
FULL LOAD DISP.	313.9	318.6	+ 4.7	321.2	+ 7.3
WT.GRP.100	50.7	51.2	+ 0.5	51.2	+ 0.5
WT.GRP.200	31.7	32.0	+ 0.3	32.2	+ 0.5
WT.GRP.300	8.6	10.6	+ 2.0	12.6	+ 4.0
WT.GRP.400	11.4	11.5	+ 0.1	11.5	+ 0.1
WT.GRP.5XX	17.2	17.4	+ 0.2	17.4	+ 0.2
WT.GRP.567	43.0	43.2	+ 0.2	43.2	+ 0.2
WT.GRP.600	18.3	18.5	+ 0.2	18.5	+ 0.2
WT.GRP.700	9.5	9.5	0.0	9.5	0.0
LIGHT SHIP	219.0	223.1	+ 4.1	225.5	+ 6.5
FUEL	74.5	75.1	+ 0.6	75.3	+ 0.9
ACT.TOTAL VOL.	46083	46414	+ 331	46555	+ 472

Table II.B.4

Space Variations for 30BL Hydrofoil

	BASELINE	+ 76 FT^2		- 319 FT^2	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF
LBP	134.2	134.7	+ 0.5	132.0	- 1.2
FULL LOAD DISP.	370.4	372.6	+ 2.2	361.0	- 9.4
WT.GRP.100	57.1	57.8	+ 0.7	54.3	- 2.8
WT.GRP.200	36.1	36.3	+ 0.2	35.6	- 0.5
WT.GRP.300	10.0	10.0	0.0	9.9	- 0.1
WT.GRP.400	11.6	11.6	0.0	11.5	- 0.1
WT.GRP.5XX	26.7	26.9	+ 0.2	25.9	- 0.8
WT.GRP.567	50.8	51.1	+ 0.3	49.5	- 1.3
WT.GRP.600	23.9	24.0	+ 0.1	23.3	- 0.6
WT.GRP.700	9.5	9.5	0.0	9.5	0.0
LIGHT SHIP	259.6	261.3	+ 1.7	252.4	- 7.2
FUEL	87.4	88.0	+ 0.6	85.3	- 2.1
ACT.TOTAL VOL.	51949	52553	+ 604	49400	-2549
REQ.TOTAL VOL.	52298	52394	+ 96	51895	- 403

Payload Weight Variations for 60BL Hydrofoil

CHARACTERISTICS	BASELINE	+ 5 TONS		+ 10 TONS		- 5 TONS		- 10 TONS	
	VALUES	NEW	DIFF	NEW	DIFF	NEW	DIFF	NEW	DIFF
LBP	171.2	171.7	+ 0.5	171.9	+ 0.7	171.1	- 0.2	170.6	- 0.6
FULL LOAD DISP.	688.6	704.8	+16.2	712.5	+23.9	675.8	-12.8	659.8	-28.8
WT.GRP.100	102.8	103.7	+ 0.9	104.1	+ 1.3	102.8	0.0	101.9	- 0.9
WT.GRP.200	56.8	57.9	+ 1.1	58.1	+ 1.3	55.9	- 0.9	54.9	- 1.9
WT.GRP.300	16.2	16.7	+ 0.5	17.2	+ 1.0	15.7	- 0.5	15.1	- 1.1
WT.GRP.400	43.2	43.2	0.0	43.2	0.0	43.2	0.0	43.2	0.0
WT.GRP.5XX	46.0	46.3	+ 0.3	46.4	+ 0.4	46.0	0.0	45.7	- 0.3
WT.GRP.567	95.1	97.3	+ 2.2	97.5	+ 2.4	93.3	- 1.8	91.1	- 4.0
WT.GRP.600	39.1	39.3	+ 0.2	39.4	+ 0.3	39.1	0.0	38.9	- 0.2
WT.GRP.700	12.4	17.4	+ 5.0	22.4	+10.0	7.4	- 5.0	2.4	-10.0
LIGHT SHIP	473.2	485.1	+11.9	492.5	+19.3	463.8	- 9.4	452.0	-21.2
FUEL	189.3	193.6	+ 4.3	194.0	+ 4.7	185.9	- 3.4	181.6	- 7.7
ACT.TOTAL VOL.	93454	94294	+ 840	94663	+1209	93413	- 41	92608	- 846
REQ.TOTAL VOL.	93714	94412	+ 698	94599	+ 885	93148	- 566	92450	-1264

Table II.B.6

Enlisted Manning Variations for 60BL Hydrofoil

CHARACTERISTICS	BASELINE VALUES	+5 MEN NEW	+5 MEN DIFF	+ 10 MEN NEW	+ 10 MEN DIFF	- 5 MEN NEW	- 5 MEN DIFF	- 10 MEN NEW	- 10 MEN DIFF
LBP	171.2	173.1	+ 1.9	174.6	+ 3.4	169.5	- 1.7	167.6	- 3.6
FULL LOAD DISP.	688.6	708.0	+19.4	731.4	+42.8	665.2	-23.4	640.8	-47.8
WT.GRP.100	102.8	106.3	+ 3.5	109.1	+ 6.3	99.9	- 2.9	96.7	- 6.1
WT.GRP.200	56.8	57.7	+ 0.9	59.1	+ 2.3	55.4	- 1.4	53.8	- 3.0
WT.GRP.300	16.2	16.5	+ 0.3	16.8	+ 0.6	15.8	- 0.4	15.5	- 0.7
WT.GRP.400	43.2	43.3	+ 0.1	43.4	+ 0.2	43.1	- 0.1	43.0	- 0.2
WT.GRP.5XY	46.0	49.2	+ 3.2	52.3	+ 6.3	42.9	- 3.1	39.8	- 6.2
WT.GRP.567	95.1	96.9	+ 1.8	100.1	+ 5.0	91.9	- 3.2	88.5	- 6.6
WT.GRP.600	39.1	41.7	+ 2.6	44.1	+ 5.0	36.6	- 2.5	34.1	- 5.0
WT.GRP.700	12.4	12.4	0.0	12.4	0.0	12.4	0.0	12.4	0.0
LIGHT SHIP	473.2	487.5	+14.3	503.0	+29.8	457.7	-15.5	441.3	-31.9
FUEL	189.3	192.7	+ 3.4	198.9	+ 9.6	183.2	- 6.1	176.8	-12.5
ACT.TOTAL VOL.	93454	96629	+3175	99208	+5754	90805	-2649	87900	-5554
REQ.TOTAL VOL.	93714	96279	+2565	99136	+5422	90783	-2931	87756	-5958

Table II.B.7

Electrical Load Variations for 60RL Hydrofoil

CHARACTERISTICS	BASELINE VALUES	+ 200 KW		+ 400 KW	
		NEW	DIFF	NEW	DIFF
LBP	171.2	171.4	+ 0.2	171.6	+ 0.4
FULL LOAD DISP.	688.2	695.1	+ 6.9	702.3	+14.1
WT.GRP.100	102.8	103.3	+ 0.5	103.8	+ 1.0
WT.GRP.200	56.8	56.9	+ 0.1	57.0	+ 0.2
WT.GRP.300	16.2	20.2	+ 4.0	24.2	+ 8.0
WT.GRP.400	43.2	43.3	+ 0.1	43.4	+ 0.2
WT.GRP.5XX	46.0	46.2	+ 0.2	46.4	+ 0.4
WT.GRP.567	95.1	95.4	+ 0.3	95.7	+ 0.6
WT.GRP.600	39.1	39.2	+ 0.1	39.3	+ 0.2
WT.GRP.700	12.4	12.4	0.0	12.4	0.0
LIGHT SHIP	473.2	479.2	+ 6.0	485.5	+12.3
FUEL	189.3	190.0	+ 0.7	191.1	+ 1.8
ACT.TOTAL VOL.	93454	93926	+ 472	94398	+ 944

Table II.B.8

Space Variations for 60BL Hydrofoil

CHARACTERISTICS	BASELINE VALUES	- 249 FT^2	
		NEW	DIFF
LBP	171.2	170.0	- 1.2
FULL LOAD DISP.	688.2	680.9	- 7.3
WT.GRP.100	102.8	100.6	- 2.2
WT.GRP.200	56.8	56.4	- 0.4
WT.GRP.300	16.2	16.1	- 0.1
WT.GRP.400	43.2	43.1	- 0.1
WT.GRP.5XX	46.0	45.3	- 0.7
WT.GRP.567	95.1	94.0	- 1.1
WT.GRP.600	39.1	38.6	- 0.5
WT.GRP.700	12.4	12.4	0.0
LIGHT SHIP	473.2	467.5	- 5.7
FUEL	189.3	187.3	- 2.0
ACT.TOTAL VOL.	93714	93398	- 316
REQ.TOTAL VOL	93454	91459	-1995

Table II.B.9

Payload Weight Variations for 240BL Hydrofoil (INITIALIZATION)

	BASELINE	+ 25 TONS		+ 42.2 TONS		- 25 TONS		- 50 TONS	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF	NEW	DIFF	NEW	DIFF
LBP	267.9	268.9	+ 1.0	269.1	+ 1.2	267.0	- 0.9	265.8	- 1.1
FULL LOAD DISP.	2425.5	2497.9	+72.4	2543.1	+117.5	2351.9	-73.6	2275.9	-149.6
WT.GRP.100	328.0	331.5	+ 3.5	332.1	+ 4.1	325.2	- 2.8	321.9	- 6.1
WT.GRP.200	155.2	158.5	+ 3.3	160.7	+ 5.5	151.7	- 3.5	148.0	- 7.2
WT.GRP.300	32.9	34.7	+ 1.8	35.8	+ 2.9	31.1	- 1.8	29.2	- 3.7
WT.GRP.400	67.5	67.7	+ 0.2	67.4	+ 0.2	67.4	- 0.1	67.3	- 0.2
WT.GRP.5XX	164.7	166.0	+ 1.3	166.2	+ 1.5	163.7	- 1.0	162.4	- 2.3
WT.GRP.567	332.3	341.5	+ 9.2	347.5	+ 15.2	322.4	-10.1	312.2	- 20.1
WT.GRP.600	123.5	124.2	+ 0.7	124.4	+ 0.9	122.8	- 0.7	122.1	- 1.4
WT.GRP.700	75.6	100.6	+25.0	117.8	+ 42.2	50.6	-25.0	25.6	- 50.0
LIGHT SHIP	1471.6	1523.4	+51.8	1555.0	+ 83.4	1420.0	-51.6	1366.9	-104.7
FUEL	788.1	808.7	+20.6	822.2	+ 34.1	766.0	-22.1	743.2	- 44.9
ACT.TOTAL VOL.	298205	301395	+3190	301926	+ 3721	295642	-2563	292592	- 5613
REQ.TOTAL VOL.	298000	300638	+2638	302320	+ 4320	295234	-2766	292358	- 5642

Table II.B.10

Payload Weight Variations for 240BL Hydrofoil (SYNTHESIS)

	BASELINE	+ 20 TONS	
CHARACTERISTICS	VALUES	NEW	DIFF
LBP	270.0	271.2	+ 0.2
FULL LOAD DISP.	2617.8	2715.7	+97.9
WT.GRP.100	318.2	324.8	+ 6.6
WT.GRP.200	239.5	250.6	+11.1
WT.GRP.300	33.1	34.5	+ 1.4
WT.GRP.400	67.8	67.9	+ 0.1
WT.GRP.5XX	167.4	169.0	+ 1.6
WT.GRP.567	342.9	358.8	+15.9
WT.GRP.600	125.1	126.0	+ 0.9
WT.GRP.700	75.6	95.6	+20.0
LIGHT SHIP	1574.8	1641.2	+66.4
FUEL	877.2	908.7	+31.5
ACT.TOTAL VOL.	304755	308522	+3767
REQ.TOTAL VOL.	304755	309183	+4428

Table II.B.11

Enlisted Manning Variations for 240BL Hydrofoil

CHARACTERISTICS	BASELINE VALUES	+ 25 MEN NEW	+ 25 MEN DIFF	+ 50 MEN NEW	+ 50 MEN DIFF	- 25 MEN NEW	- 25 MEN DIFF	- 50 MEN NEW	- 50 MEN DIFF
LBP	267.9	272.3	+ 4.4	276.4	+ 8.5	262.8	- 5.1	257.6	- 7.7
FULL LOAD DISP.	2425.5	2550.6	+125.1	2663.4	+237.9	2297.9	-127.6	2167.0	-258.5
WT.GRP.100	328.0	343.4	+ 15.4	358.0	+ 30.0	312.1	- 15.9	295.5	- 32.5
WT.GRP.200	155.2	160.8	+ 5.6	165.4	+ 10.2	149.4	- 5.8	143.4	- 11.8
WT.GRP.300	32.9	34.0	+ 1.1	35.2	+ 2.3	31.7	- 1.2	30.4	- 2.5
WT.GRP.400	67.5	68.1	+ 0.6	68.6	+ 1.1	67.0	- 0.5	66.4	- 1.1
WT.GRP.5XX	164.7	181.3	+ 16.6	197.7	+ 32.0	147.9	- 16.8	130.9	- 33.8
WT.GRP.567	332.3	348.9	+ 16.6	362.6	+ 30.3	315.2	- 17.1	297.7	- 34.6
WT.GRP.600	123.5	135.9	+ 12.4	148.1	+ 24.6	110.9	- 12.6	98.2	- 25.3
WT.GRP.700	75.6	75.6	0.0	75.6	0.0	75.6	0.0	75.6	0.0
LIGHT SHIP	1471.6	1550.2	+ 78.6	1622.8	+151.2	1391.4	- 80.2	1309.0	-162.4
FUEL	788.1	824.9	+ 36.8	855.4	+ 67.3	750.4	- 37.7	711.5	- 76.6
ACT.TOTAL VOL.	298205	312156	+13951	325418	+27213	283761	-14444	268641	-29564
REQ.TOTAL VOL.	298000	312067	+14067	325294	+27294	283570	-14430	268657	-29343

Table II.B.12

Electrical Load Variations for 240PL Hydrofoil

	BASELINE	+ 300 KW		+ 750 KW	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF
LBP	267.9	268.0	+ 0.1	268.2	+ 0.3
FULL LOAD DISP.	2425.5	2435.6	+10.1	2449.8	+24.3
WT.GRP.100	328.0	328.8	+ 0.8	330.0	+ 2.0
WT.GRP.200	155.2	155.3	+ 0.1	155.4	+ 0.2
WT.GRP.300	32.9	38.9	+ 6.0	47.9	+15.0
WT.GRP.400	67.5	67.6	+ 0.1	67.7	+ 0.2
WT.GRP.5XX	164.7	165.0	+ 0.3	165.3	+ 0.6
WT.GRP.567	332.3	332.7	+ 0.4	333.1	+ 0.8
WT.GRP.600	123.5	123.6	+ 0.1	123.7	+ 0.2
WT.GRP.700	75.6	75.6	0.0	75.6	0.0
LIGHT SHIP	1471.6	1480.6	+ 9.0	1493.5	+21.9
FUEL	788.1	789.2	+ 1.1	790.5	+ 2.4
ACT.TOTAL VOL.	298205	298913	+ 708	299975	+1770

Table II.B.13

Space Variations 240BL Hydrofoil

	BASELINE	+ 98 FT^2		+ 819 FT^2	
CHARACTERISTICS	VALUES	NEW	DIFF	NEW	DIFF
LBP	267.9	268.1	+ 0.2	270.0	+ 2.1
FULL LOAD DISP.	2425.5	2428.6	+ 3.1	2452.7	+27.2
WT.GRP.100	328.0	328.9	+ 0.9	335.2	+ 7.2
WT.GRP.200	155.2	155.3	+ 0.1	156.6	+ 1.4
WT.GRP.300	32.9	32.9	0.0	33.1	+ 0.2
WT.GRP.400	67.5	67.6	+ 0.1	67.8	+ 0.3
WT.GRP.5XX	164.7	165.0	+ 0.3	167.4	+ 2.7
WT.GRP.567	332.3	332.7	+ 0.4	335.5	+ 3.2
WT.GRP.600	123.5	123.6	+ 0.1	125.1	+ 1.6
WT.GRP.700	75.6	75.6	0.0	75.6	+ 0.0
LIGHT SHIP	1471.6	1473.8	+ 2.2	1490.8	+19.2
FUEL	788.1	789.0	+ 0.9	796.1	+ 8.0
ACT.TOTAL VOL.	298205	298970	+ 765	304755	+6550
REQ.TOTAL VOL.	298000	298115	+ 115	298988	+ 988

APPENDIX III

Tables of Data

For

Surface Effect Ships

Table III.1

Payload Weight Variation for SES1

CHARACTERISTICS	BASELINE VALUES	+ 5 TONS	
		NEW	DIFF
LBP	128.7	129.3	+ 1.6
L/B	3.35	3.33	-0.02
FULL LOAD DISP.	645.4	661.3	+15.9
WT.GRP.100	134.7	137.4	+ 2.7
WT.GRP.200	118.6	120.5	+ 1.9
WT.GRP.300	8.1	8.3	+ 0.2
WT.GRP.400	5.4	5.4	0.0
WT.GRP.5XX	30.3	31.2	+ 0.9
WT.GRP.567	45.8	45.8	0.0
WT.GRP.600	35.7	36.8	+ 1.1
WT.GRP.700	20.0	25.0	+ 5.0
LIGHT SHIP	457.8	471.9	+14.1
FUEL	98.9	100.8	+ 1.9
CUSH PRESS	287.6	290.3	+ 3.3

Table III.2

Enlisted Manning Variation for SES1

CHARACTERISTICS	BASELINE VALUES	+ 5 MEN	
		NEW	DIFF
LBP	128.7	128.9	+ 0.2
L/B	3.35	3.34	-0.01
FULL LOAD DISP.	645.4	650.1	+ 4.7
WT.GRP.100	134.7	135.2	+ 0.5
WT.GRP.200	118.6	119.2	+ 0.6
WT.GRP.300	8.1	8.2	+ 0.1
WT.GRP.400	5.4	5.4	0.0
WT.GRP.5XX	30.3	30.4	+ 0.1
WT.GRP.567	45.8	45.8	0.0
WT.GRP.600	35.7	35.8	+ 0.1
WT.GRP.700	20.0	20.0	0.0
LIGHT SHIP	457.8	459.9	+ 2.1
FUEL	98.9	99.5	+ 0.6
CUSH PRESS	287.6	288.4	+ 0.8

Table III.3

Electrical Load Variation for SES1

CHARACTERISTICS	BASELINE VALUES	+ 95 KW NEW	DIFF
LBP	128.8	128.9	+ 0.1
L/B	3.35	3.34	-0.01
FULL LOAD DISP.	645.4	651.8	+ 6.4
WT.GRP.100	134.7	135.4	+ 0.7
WT.GRP.200	118.6	119.5	+ 0.9
WT.GRP.300	8.1	10.2	+ 2.1
WT.GRP.400	5.4	5.4	0.0
WT.GRP.5XX	30.3	30.7	+ 0.4
WT.GRP.567	45.8	45.8	0.0
WT.GRP.600	35.7	36.1	+ 0.4
WT.GRP.700	20.0	20.0	0.0
LIGHT SHIP	457.8	463.5	+ 5.7
FUEL	98.9	99.8	+ 0.9
CUSH PRESS	287.6	289.0	+ 1.4

Table III.4

Space Variation for SES1

CHARACTERISTICS	BASELINE VALUES	+ 300 FT^2	
		NEW	DIFF
LBP	128.8	132.5	+ 3.7
L/B	3.35	3.35	0.0
FULL LOAD DISP.	645.4	646.8	+ 1.4
WT.GRP.100	134.7	141.9	+ 7.2
WT.GRP.200	118.6	114.4	- 4.2
WT.GRP.300	8.1	8.2	+ 0.1
WT.GRP.400	5.4	5.4	0.0
WT.GRP.5XX	30.3	30.6	+ 0.3
WT.GRP.567	45.8	45.8	0.0
WT.GRP.600	35.7	36.0	+ 0.3
WT.GRP.700	20.0	20.0	0.0
LIGHT SHIP	457.8	462.6	+ 4.8
FUEL	98.9	95.6	- 3.3
CUSH PRESS	287.6	271.8	-15.8

Table III.5

Payload Weight Variations for SES3

CHARACTERISTICS	BASELINE VALUES	- 30 TONS NEW	- 30 TONS DIFF	+ 30 TONS NEW	+ 30 TONS DIFF	+ 60 TONS NEW	+ 60 TONS DIFF
LBP	235.8	233.7	- 2.1	237.9	+ 2.1	240.1	+ 4.3
L/B	2.59	2.61	+ 0.02	2.56	- 0.03	2.53	- 0.06
FULL LOAD DISP.	3864.9	3699.8	-165.1	4031.8	+166.9	4200.7	+335.8
WT.GRP.100	1002.4	963.3	- 39.1	1042.4	+ 40.0	1083.4	+ 81.0
WT.GRP.200	350.0	337.7	- 12.3	362.4	+ 12.4	374.7	+ 24.7
WT.GRP.300	74.7	71.1	- 3.8	78.7	+ 3.8	82.5	+ 7.6
WT.GRP.400	74.0	74.0	0.0	74.0	0.0	74.0	0.0
WT.GRP.5XX	125.4	119.1	- 6.3	131.8	+ 6.4	138.3	+ 12.9
WT.GRP.567	127.4	127.4	0.0	127.4	0.0	127.4	0.0
WT.GRP.600	218.4	207.4	- 11.0	229.4	+ 11.0	240.6	+ 22.2
WT.GRP.700	63.0	33.0	- 30.0	93.0	+ 30.0	123.0	+ 60.0
LIGHT SHIP	2341.0	2223.2	-117.8	2460.2	+119.2	2580.7	+239.7
FUEL	1285.2	1237.9	- 47.3	1332.9	+ 47.7	1381.3	+ 96.1
CUSH PRESS	366.8	360.0	- 6.8	373.3	+ 6.5	379.5	+ 12.7

Table III.6

Enlisted Manning Variations for SES3

CHARACTERISTICS	BASELINE VALUES	- 25 MEN		+ 25 MEN	
		NEW	DIFF	NEW	DIFF
LBP	235.8	235.3	- 0.5	236.3	+ 0.5
L/B	2.59	2.59	0.0	2.58	-0.01
FULL LOAD DISP.	3864.9	3825.2	-39.7	3904.8	+39.9
WT.GRP.100	1002.4	993.0	- 9.4	1011.9	+ 9.5
WT.GRP.200	350.0	347.1	- 2.9	353.0	+ 3.0
WT.GRP.300	74.9	74.3	- 0.6	75.5	+ 0.6
WT.GRP.400	74.0	74.0	0.0	74.0	0.0
WT.GRP.5XX	125.4	124.5	- 0.9	126.4	+ 1.0
WT.GRP.567	127.4	127.4	0.0	127.4	0.0
WT.GRP.600	218.4	216.7	- 1.7	220.0	+ 1.6
WT.GRP.700	63.0	63.0	0.0	63.0	0.0
LIGHT SHIP	2341.0	2313.0	-18.0	2359.1	+18.1
FUEL	1285.2	1273.8	-11.4	1296.6	+11.4
CUSH PRESS	366.8	365.2	- 1.6	368.4	+ 1.6

Table III.7

Electrical Load Variations for SES3

CHARACTERISTICS	BASELINE	+ 250 KW		+ 500 KW	
	VALUES	NEW	DIFF	NEW	DIFF
LBP	235.8	236.0	+ 0.2	236.2	+ 0.4
L/B	2.59	2.58	-0.01	2.57	-0.02
FULL LOAD DISP.	3864.9	3892.8	+27.9	3921.3	+56.4
WT.GRP.100	1002.4	1008.3	+ 5.9	1014.3	+11.9
WT.GRP.200	350.0	352.3	+ 2.3	354.7	+ 4.7
WT.GRP.300	74.9	80.5	+ 5.6	86.3	+11.4
WT.GRP.400	74.0	74.0	0.0	74.0	0.0
WT.GRP.5XX	125.4	126.5	+ 1.1	127.5	+ 2.2
WT.GRP.567	127.4	127.4	0.0	127.4	0.0
WT.GRP.600	218.4	220.1	+ 1.7	222.0	+ 3.6
WT.GRP.700	63.0	63.0	0.0	63.0	0.0
LIGHT SHIP	2341.0	2360.1	+19.1	2379.7	+38.7
FUEL	1285.2	1293.9	+ 8.7	1302.8	+17.6
KW LOAD	3745	4026	+ 281	4314	+ 569
CUSH PRESS	366.8	368.3	+ 1.5	369.8	+ 3.0

Table III.8

Space Variations for SES3

CHARACTERISTICS	BASELINE VALUES	$-1009\ FT^2$		$+990\ FT^2$	
		NEW	DIFF	NEW	DIFF
LBP	235.8	230.1	- 5.7	241.1	+ 11.0
L/B	2.59	2.58	- 0.01	2.58	- 0.01
FULL LOAD DISP.	3864.9	3970.8	+105.9	4051.1	+186.2
WT.GRP.100	1002.4	991.7	- 10.7	1092.2	+ 89.8
WT.GRP.200	350.0	377.2	+ 27.2	360.6	+ 10.6
WT.GRP.300	74.9	75.7	+ 0.8	79.5	+ 4.6
WT.GRP.400	74.0	74.0	0.0	74.0	0.0
WT.GRP.5XX	125.4	126.7	+ 1.3	133.2	+ 7.8
WT.GRP.567	127.4	127.4	0.0	127.4	0.0
WT.GRP.600	218.4	220.6	+ 2.2	231.9	+ 13.5
WT.GRP.700	63.0	63.0	0.0	63.0	0.0
LIGHT SHIP	2341.0	2364.9	+ 23.9	2486.3	+145.3
FUEL	1285.2	1367.2	+ 82.0	1326.2	+ 41.0
CUSH AREA	21504	20495	- 1009	22494	+ 990
CUSH PRESS	366.8	397.2	+ 30.4	368.5	+ 1.7

Table III.9

Combined Variation of +45 Tons Payload Weight, +8 Men, and +350 KW on SES3

CHARACTERISTICS	BASELINE VALUES	+ 45 TONS/+ 8 MEN/ + 350 KW	
		NEW	DIFF
LBP	235.8	239.4	+ 3.6
L/B	2.59	2.54	- 0.05
FULL LOAD DISP.	3864.9	4172.2	+307.3
WT.GRP.100	1002.4	1075.2	+ 72.8
WT.GRP.200	350.0	373.0	+ 23.0
WT.GRP.300	74.9	89.4	+ 14.5
WT.GRP.400	74.0	74.0	0.0
WT.GRP.5XX	125.4	136.9	+ 11.5
WT.GRP.567	127.4	127.4	0.0
WT.GRP.600	218.4	238.3	+ 19.9
WT.GRP.700	63.0	108.0	+ 45.0
LIGHT SHIP	2341.0	2555.8	+214.8
FUEL	1285.2	1374.3	+ 89.1
CUSH PRESS	366.8	379.0	- 12.2

Table III.10

Payload Weight Variations for SES4

CHARACTERISTICS	BASELINE VALUES	- 30 TONS		+ 30 TONS		+ 60 TONS	
		NEW	DIFF	NEW	DIFF	NEW	DIFF
LBP	257.9	257.9	0.0	257.9	0.0	257.9	0.0
L/B	2.87	2.87	0.0	2.87	0.0	2.87	0.0
FULL LOAD DISP.	4271.7	4092.9	-178.8	4461.8	+190.1	4664.8	+393.1
WT.GRP.100	1202.1	1179.6	- 22.5	1225.5	+ 23.5	1249.9	+ 47.9
WT.GRP.200	354.8	334.3	- 20.5	377.3	+ 22.5	402.0	+ 47.2
WT.GRP.300	84.4	81.0	- 3.4	87.9	+ 3.5	91.5	+ 7.1
WT.GRP.400	74.0	74.0	0.0	74.0	0.0	74.0	0.0
WT.GRP.5XX	141.3	135.6	- 5.7	147.2	+ 5.9	153.3	+ 12.0
WT.GRP.567	127.4	127.4	0.0	127.4	0.0	127.4	0.0
WT.GRP.600	245.9	236.0	- 9.9	256.1	+ 10.2	266.7	+ 20.8
WT.GRP.700	63.0	33.0	- 30.0	93.0	+ 30.0	123.0	+ 60.0
LIGHT SHIP	2636.9	2531.2	-105.7	2746.8	+109.9	2861.2	+224.3
FUEL	1396.1	1323.0	- 73.1	1476.4	+ 80.3	1564.9	+168.8
CUSH PRESS	376.2	358.9	- 17.3	394.5	+ 18.3	414.1	+ 37.9

Table III.11

Enlisted Manning Variations for SES4

CHARACTERISTICS	BASELINE VALUES	+ 35 MEN		+ 70 MEN	
		NEW	DIFF	NEW	DIFF
LPP	257.9	257.9	0.0	257.9	0.0
L/B	2.87	2.87	0.0	2.87	0.0
FULL LOAD DISP.	4271.7	4334.2	+ 62.5	4398.0	+126.3
WT.GRP.100	1202.1	1209.9	+ 7.8	1217.7	+ 15.6
WT.GRP.200	354.8	362.1	+ 7.3	369.7	+ 14.9
WT.GRP.300	84.4	85.0	+ 0.6	85.8	+ 1.4
WT.GRP.400	74.0	74.0	0.0	74.0	0.0
WT.GRP.5XX	141.3	142.5	+ 1.2	143.6	+ 2.3
WT.GRP.567	127.4	127.4	0.0	127.4	0.0
WT.GRP.600	245.9	247.9	+ 2.0	250.0	+ 4.1
WT.GRP.700	63.0	63.0	0.0	63.0	0.0
LIGHT SHIP	2636.9	2658.7	+ 21.8	2681.0	+ 44.1
FUEL	1396.1	1422.2	+ 26.1	1449.1	+ 53.0
CUSH PRESS	376.2	382.2	+ 6.0	388.4	+ 12.2

Table III.12

Electrical Load Variations for SES4

CHARACTERISTICS	BASELINE	+ 250 KW		+ 500 KW	
	VALUES	NEW	DIFF	NEW	DIFF
LBP	257.9	257.9	0.0	257.9	0.0
L/B	2.87	2.87	0.0	2.87	0.0
FULL LOAD DISP.	4271.7	4302.8	+ 31.1	4334.6	+ 62.9
WT.GRP.100	1202.1	1205.8	+ 3.7	1209.9	+ 7.8
WT.GRP.200	354.8	358.5	+ 4.0	362.2	+ 7.4
WT.GRP.300	84.4	90.0	+ 5.6	95.7	+ 11.3
WT.GRP.400	74.0	74.0	0.0	74.0	0.0
WT.GRP.5XX	141.3	142.3	+ 1.0	143.2	+ 1.9
WT.GRP.567	127.4	127.4	0.0	127.4	0.0
WT.GRP.600	245.9	247.6	+ 1.7	249.3	+ 3.4
WT.GRP.700	63.0	63.0	0.0	63.0	0.0
LIGHT SHIP	2636.9	2655.1	+ 18.2	2673.6	+ 36.7
FUEL	1396.1	1409.0	+ 12.9	1422.4	+ 26.3
CUSH PRESS	376.2	379.2	+ 3.0	382.2	+ 6.0

Table III.13

Space Variations for SES4

CHARACTERISTICS	BASELINE VALUES	+ 1160 FT^2	
		NEW	DIFF
LBP	257.9	270.9	+ 13.0
L/B	2.87	3.0	+ 0.13
FULL LOAD DISP.	4271.7	4279.2	+ 7.5
WT.GRP.100	1202.1	1246.3	+ 44.2
WT.GRP.200	354.8	344.9	- 9.9
WT.GRP.300	84.4	85.9	+ 1.5
WT.GRP.400	74.0	74.0	0.0
WT.GRP.5XX	141.3	143.9	+ 2.6
WT.GRP.567	127.4	127.4	0.0
WT.GRP.600	245.9	250.5	+ 4.6
WT.GRP.700	63.0	63.0	0.0
LIGHT SHIP	2636.9	2686.6	+ 50.3
FUEL	1396.1	1353.9	- 42.2
CUSH PRESS	376.2	357.4	- 18.8

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Marginal cost factors for high performance ships and their impact on subsystem design.